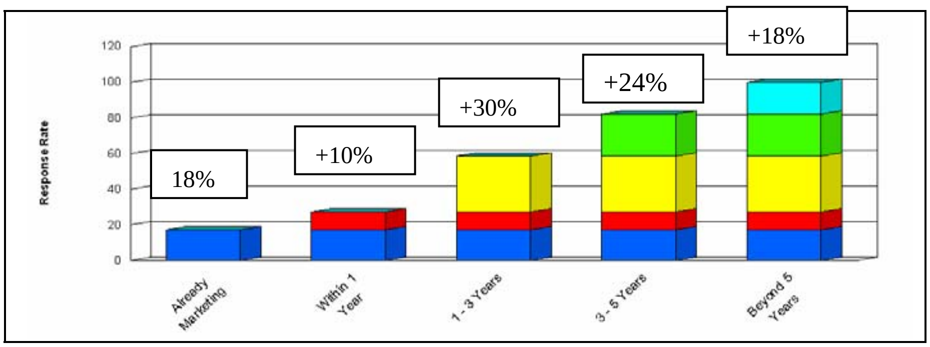
2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry

(Sponsored by NSF)



New Nanoproducts Commercialization Between 2007-2011

Final Report

June 2006

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Preface

Organizations involved in the rapidly expanding U.S. Nanomanufacturing Industry have similar goals and face similar challenges, regardless of their geographic location or application market. The NSF-sponsored 2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry received inputs from nearly 600 senior level executives with leadership, technology or strategic R&D responsibility in leading U.S. organizations, and the results reflect the outcome of growing public and private investments made in nanotechnology. This report attempts to document many of the key trends and industry concerns, including one such challenge – the need for increased information about the Industry.

The report serves as a benchmark of the U.S. Nanomanufacturing Industry, as well as profiles the major issues it faces, relative to the diverse stakeholder organizations, nanotechnology product types, lead times, early adopter/application markets, and geographical regions involved in the global transition to nanomanufacturing. Industry trends have been mapped based on the following several strategic indicators of R&D, commercialization and performance as this new sector evolves and matures:

- Corporate urgency
- Change management
- Internal capacity
- Infrastructure
- Time-to-market
- Staffing
- Collaboration and partnering
- Public policy
- Industry barriers and impediments
- Technology transfer mechanisms.

Acknowledgments

The NCMS gratefully acknowledges the sponsorship of the National Science Foundation (Award # DMI-0450666), as well as the crucial guidance received from Dr. Mike Roco, Senior Advisor for Nanotechnology, and Mr. Kevin Lyons, Program Director, Nanomanufacturing.

Our thanks are also due to Ascendus Technologies for survey design, Small Times Media LLC, and all organizations associated with dissemination of the survey, as well as to the nearly 600 survey respondents plus additional interviewees for their time and valuable insights.

Mrs. Anita Tolen, NCMS, provided vital compilation and editorial assistance.

About NCMS

The National Center for Manufacturing Sciences (NCMS) is a not-for-profit organization, based in Ann Arbor, MI, and is a premier provider of collaborative research, information, knowledge and expertise to the North American manufacturing and defense community. Now in its 20th year, NCMS has spearheaded numerous advancements – in advanced materials, alternative energy, electronics, high-performance machining, process control, rapid prototyping, lean manufacturing, enterprise integration, information technology, and environmental conscientiousness – all focused on enhancing the nation's manufacturing competitiveness in the global economy,

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Acronyms and Abbreviations

2D	two-dimensional
3D	three-dimensional
FDA	Food and Drug Administration
IP	intellectual property
IPO	initial public offering
IT	information technology
MEMS	micro electro-mechanical systems
NACFAM	National Coalition for Advanced Manufacturing
NCMS	National Center for Manufacturing Sciences
NDE	Nano Data Explorer
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NSEC	Nanoscale Science and Engineering Centers
NSF	National Science Foundation
OEM	original equipment manufacturer
R&D	research and development
RFID	radio-frequency identification
SBA	Small Business Association
SBIR	Small Business Innovative Research
STTR	Small Business Technology Transfer Research
U.S.	United States
VC	venture capital

1. Executive Summary

1.1 Background

In 2005, the National Science Foundation (NSF) awarded a grant to the National Center for Manufacturing Sciences (NCMS) to poll over 6,000 senior-level executives in leading U.S. organizations with leadership, technology or strategic research and development (R&D) responsibility to assess the outcome of growing private and public investments made in nanotechnology under the National Nanotechnology Initiative (NNI). The overarching objective in conducting this largest known cross-industry benchmark study was to determine whether surveyed organizations treat nanotechnology differently from any other generation of advanced science and technology. The metric established by NSF was 300 survey responses to develop a credible profile – the survey netted 594 completed responses, representing a response rate of 10%.

1.2 Aggregate Observations

The NCMS survey of nearly 600 industry executives indicates that the state of the U.S. Nanomanufacturing Industry is generally vital, innovative and competitive for demonstrated passive nanotechnology products with many two-dimensional (2D) product applications growing rapidly for end-uses across diverse industry sectors. The survey confirms that the U.S. has the best-developed and mature research facilities, entrepreneurial culture and governance infrastructure for promoting new nanotechnology-driven economic development.

1.2.1 Proliferation of Nanotechnology Start-ups

Besides the numerous entrepreneurial start-ups and small businesses (often led by researchers with academic or government laboratory connections), many larger manufacturers of conventional industrial materials and products as well as original equipment manufacturers (OEMs) and end-users, have begun to pursue internal research, actively seek new technologies, and partner in order to evaluate the potential for incorporating nanotechnology in differentiating their current product lines. Some of the world's largest manufacturing organizations are actively developing their own pipelines and strategies for future products by adopting the specialized techniques to leverage risks and penetrate new markets with nanotechnology. Corporate partnering is critical for embryonic nanotechnology businesses to attain growth and viability; it begins anywhere from peer relationships to technology co-development and co-marketing, to culmination in merger and acquisition.

1.2.2 Diverse Nanotechnology Products in Development

Aggregate survey responses indicated that the U.S. Pacific region leads the Nation in development of diverse nanotechnology products and application markets that are being pursued for potentially disruptive economic, social, environmental and military advantage (Figure 1-1). Table 1-1 lists these applications. The U.S. leads the world in the generation and commercialization of nanoscale materials, manipulation tools and measurement innovations being applied to initially benefit a growing range of consumer products, digital storage, photovoltaic and semiconductor manufacturing industries. Myriad new applications of advanced nanocoatings, nanofilms and nanoparticles are being developed for introduction in the near-term (3-5 years) on a broader range of durable goods, consumer electronics and medical products (Figure 1-2). Nanoproduct applications are also being developed for the next generation semiconductor, energy, chemical catalysis and pharmaceutical/biomedical products. These would eventually mature into convergence products with higher sensory complexity, self-assembly and autonomous functionality, offering

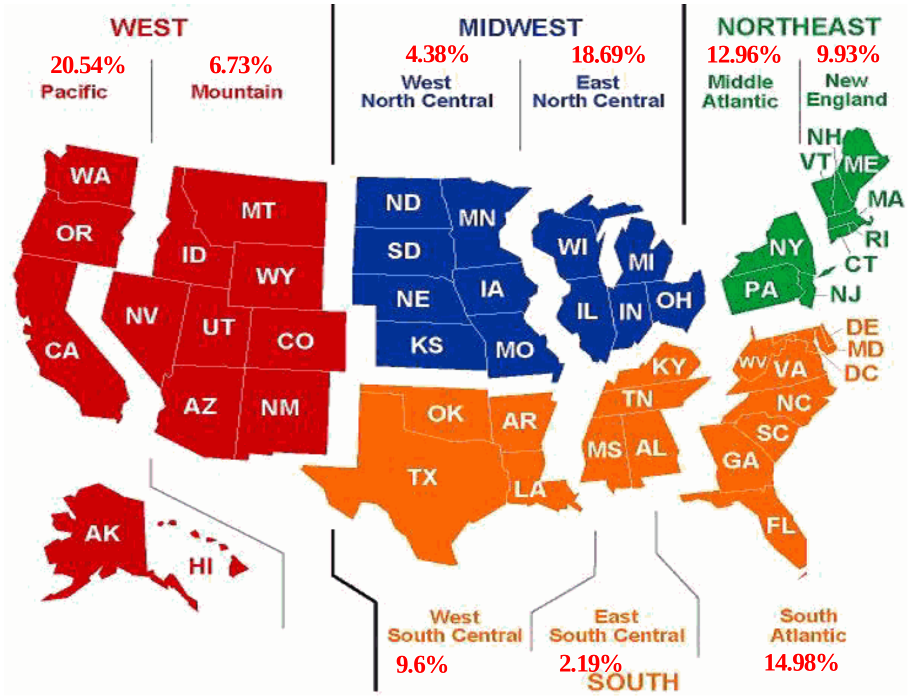


Figure 1-1. Geographical Distribution of 594 Respondents Corresponds Closely with Major Public Investments in Nanotechnology

Table 1-1. Nanotechnology Products and Major Application Markets
(Primary markets are shown in green, as indicated by aggregate survey responses)

Nanotechnology Products and Major Application Markets	APPLICATION MARKET(S)	Nano-Tools, Equipment, Logistics	Electronics & Semiconductors	Computing, IT & Telecom	Aerospace	Automotive	Chemicals & Processing	Sensing, Environmental & Security	Energy & Utilities	Fabricated Products	Consumer Products & Textiles	Pharma, Biomedical & Biotech	Off-Highway & Transportation	Machine-tools & Machinery	Housing & Construction	Food & Agriculture	Metals, Mining & Material Production
NANOTECHNOLOGY PRODUCT(S)																	
Semiconductors, Nanowires, Lithography & Print Products		X	X	X	X	X	X	X	X	X	X	X		X			X
Coatings, Paints, Thin-films and Particulates		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nano-structured Particles, Nanotubes & Self-Assembly		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Drug Delivery & Diagnostic Systems, Medical Implants		X	X	X			X	X		X	X	X				X	
Nano-Bio, Nanofluidics & Tissue Engineering Products		X	X	X				X		X	X	X				X	
Catalysis, Battery, Fuel Cell & Filtration Products		X				X	X	X	X	X	X	X	X			X	X
Environmental Sensing & Remediation Products		X	X		X	X	X	X	X	X	X	X	X			X	X
Defense, Security & Protection Gear		X	X		X	X		X	X	X	X	X					X
Electronic Devices, Displays & Optoelectronics		X	X	X	X	X		X	X	X	X	X				X	
Nano-Manipulation, Visualization, Biomarkers, Q-Dots		X	X	X			X	X		X	X	X		X		X	X
Computing, Design, Imaging Tools & Products			X	X													
Personal Care, Nanofluids & Colloids							X				X	X				X	X
Convergence Products (Nano-Bio-IT-Cognitive)				X								X					
Other																X	

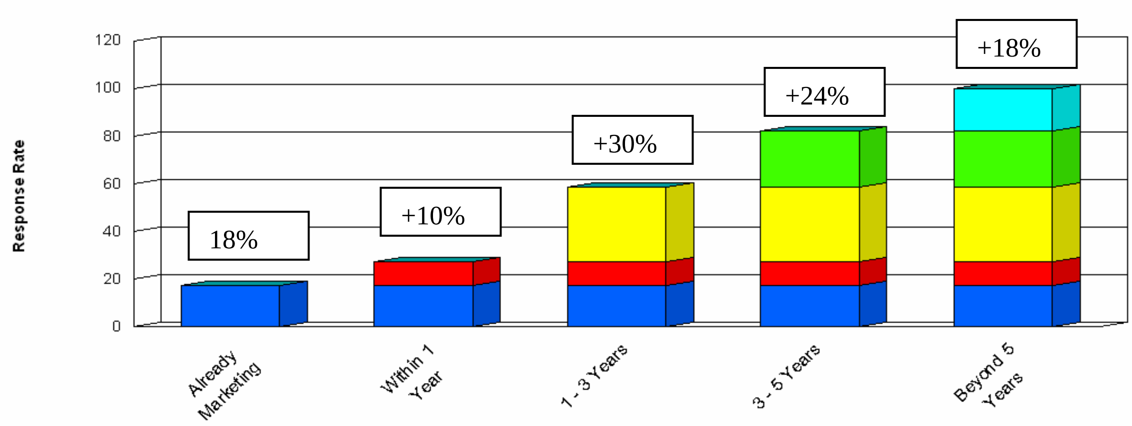


Figure 1-2. Commercialization Timelines Indicate Many New Nanoproducts Introductions in 2007-2011

greater potentials for achieving the envisioned economic and societal impact.

1.2.3 Few Early Successes, Many Barriers

Organizations are proceeding cautiously in the development and commercialization of innovations such as active three-dimensional (3D) nanotechnology products that involve more direct human, societal and environmental impact. The nanomanufacturing industry for second generation (potentially disruptive) nanotechnology products is largely in its infancy – there are as yet no commercial devices based on true nanotechnology. The challenges facing the industry are not limited to the technology itself – rather, factors such as funding, commercialization strategies, regulation and a variety of socio-business issues will affect the long-term success of organizations entering this domain.

Due to the cross-disciplinary nature and broad societal implications of nanotechnology, few organizations possess the vertical integration and expertise needed to rapidly commercialize the envisioned second generation nanoproducts from conception to consumption. While there is much exploratory partnering and co-development within the industry, it will accelerate when the early nanotechnology applications transcending lengths of scale are able to demonstrate unquestionably superior performance of existing macro-scale products and systems at affordable cost, improved margins and higher reliability.

Large-scale, market-driven investments have been somewhat inhibited due to the lack of broader, in-depth understanding of nanotechnology's complex material-process-property phenomena and its interactions with humans and the environment. These issues uphold the perception of uncertainty and long lead times in the industry. Therefore, the near-term impact of nanotechnology is likely to be fragmented, product-specific and evolutionary rather than revolutionary. The distillation of survey trends and executive attitudes indicates that while new applications will grow in the near-term largely by entrepreneurial means (e.g. technology push to seek niche applications), the longer-term success of a nanomanufacturing venture would depend on an organization's core competency to partner with end-users and technology providers on the basis of platform nanotechnologies as well as its ability to meet defined performance objectives (i.e. market pull factors) that help meet the customers' bottom-line.

1.2.4 Increased Corporate and Public Awareness

Traditional manufacturing organizations, while interested in adopting nanotechnology, tend to be preoccupied with issues of short-term profitability and other approaches that prioritize returns and revenues over long-term growth (such as innovation and skills development). Recent pronouncements of the importance of nanotechnology herald a significant change in corporate and National attitudes. For prepared organizations, these trends represent new opportunity for paradigm shifts in change management to drive innovations for superior product lines, and realize improved investment returns on a global scale.

These positive trends are attributed in large part to the substantial seed investments, leadership and outreach efforts made by the NNI through R&D undertaken across academia, small and large businesses and the National Laboratory infrastructure. Concurrently, the increased branding of leading-edge consumer products and coining of science fiction terms with "nano" have also raised societal awareness, albeit with mixed results. They have the longer-term impact of preparing both, a new generation of knowledge workers and informed consumers.

Survey respondents unanimously indicated that sustained government sponsorship is essential to attract the attention of senior manufacturing industry executives, investors, media and the public. Government support will expedite improved fundamental understanding of nanotechnology and further clarify its potential, while fostering both, early markets and entrepreneurship towards the more advanced generation product applications.

1.3 Addressing Key Industry Barriers

The majority of the surveyed executives indicated their organizations faced considerable difficulty in nanomanufacturing, ranging from emergent technology issues, to raising capital for critical infrastructure investments, attracting the technical and business talent, connecting with early end-users, and producing competitively to meet new market applications and volumes.

Intellectual property (IP) issues and the sharing of knowledge were identified as areas of significant concern, as well as the lack of clear regulatory policy, which could impede industry, and impact the public's reaction to future product developments. The continued education of the public, policymakers (State and Federal), government agencies and legislative bodies regarding these issues will result in clearer product approval pathways, robust standards and responsible practices, and thereby help ensure the continued dominance of the U.S.

While the nanomanufacturing industry faces unique challenges, similarities do exist with other recent technology waves such as the Internet and biotechnology, offering many lessons learned for formulation of sound anticipatory approaches. The answers to addressing the top-ranked challenges lie in continuing the aggressive National R&D investment policies for pursuing targeted investigations in fundamental nanoscale science, engineering and manufacturing technology. NCMS recommends several approaches for addressing the technology and business needs of the U.S. Nanomanufacturing Industry, while responsibly accelerating the benefits of new or enhanced products for societal benefit. NCMS further recommends the reclassification of the conventional definition of "small" business, as many of the largest organizations working with nanotechnologies would be considered small businesses by traditional industry standards. The following three broad categories are suggested in addressing the unique needs of current generation of embryonic nanotechnology businesses:

- Small nanotechnology businesses (less than 20 staff)
- Medium nanotechnology businesses (21 – 100 staff)
- Large nanotechnology businesses (over 100 staff).

Table 1-2 lists several approaches and National strategies for addressing clusters of identified barriers to the nanomanufacturing industry.

1.4 Accelerating Nanotechnology Developments

In order to maintain the current high momentum of innovation in nanotechnology advances critical investment, business and regulation-related issues need to be addressed concurrently and collaboratively by State and Federal policymakers. Long-term policies for National investment and the stimulation of public-private-research partnerships are imperative for developing the fundamental science base, facilitating technology transition to applied research, and demonstrating credible nanotechnology-enabled applications that are perceived as meaningful to our quality of life. The potential risks and hazards associated with the more revolutionary envisioned nanotechnology applications need to be assessed and disseminated by trusted sources to raise the public's awareness, and thereby gain societal confidence. Strong incentives will help resulting innovations become swiftly translated into industry-led technology demonstrations that enhance the public's awareness and acceptance. This will require dramatic changes in business strategy and unprecedented levels of public-private regulatory collaborations to responsibly commercialize future nanoproduct applications. Such levels of integration do not presently exist.

1.4.1 Public-Private Collaborations

It is unlikely that the vast field of nanotechnology would reach the levels of maturity (like other traditional physical science-based industries did) within our lifetimes. This justifies the case for long-term government investment in nanotechnology. Private and institutional investments

Table 1-2. Strategies to Address Critical Identified Barriers Faced by the U.S. Nanomanufacturing Industry

INDUSTRY BARRIER(S)	RECOMMENDATION(S)
High cost of processing/ Process scalability issues/ Lack of development tools	▪ Collaborative R&D in value-chains ▪ R&D to reduce/combine process steps ▪ R&D in new equipment and to improve product yields
Long time-to-market/ Unclear societal benefits	▪ Government incentives for private R&D investments ▪ Raise public awareness of benefits via successes ▪ Promote supplier/end-user partnerships
Insufficient investment capital	▪ Government investment in pre-competitive R&D ▪ Stimulate market pull via end-users ▪ Mentor start-ups for attracting investment
Intellectual Property (IP) issues	▪ New business models for nanotech value-chains ▪ Legal reform, train legal and judicial professionals ▪ Streamline partnering with academia and National Labs ▪ Facilitate supplier/end-user partnerships
Shortage of qualified manpower/ Multi-disciplinary aspects	▪ Retrain tech workforce in basic science/testing/quality ▪ Attract students to science and engineering careers
Regulatory and safety concerns/ Environmental and toxicity issues	▪ Streamline permit/product approvals at agencies ▪ Increase government-sponsored R&D ▪ Broader dissemination of findings ▪ Balanced legislation and regulatory practices

would grow faster when some of the fundamental technical issues of process scalability and cost of production of new nano-components as well as associated risks have been more comprehensively addressed.

Public-private collaborations in applied nanotechnology will hasten societal support when targeted towards nearer-term National concerns such as:

- Increasing productivity and profitability in manufacturing
- Improving energy resources and utilization
- Reducing environmental impact
- Enhancing healthcare with better pharmaceuticals
- Improving agriculture and food production
- Expanding the capabilities of computational and information technologies.

1.4.2 Critical Role of Government

Government can lead by defining and funding National priorities, and creating meaningful grand challenge incentives for early industrial adopters of nanotechnology. This will accelerate the broad-based translation of nanotechnology advances across multiple industry sectors.

Areas where greater government involvement in nanotechnology can have high National impact while leveraging substantially larger private investments include:

1. Incentives favoring longer-term investments (e.g. tax-free bonds for financing, tax credits for capital investments, reduced capital gains tax rates, investment-specific loan guarantees, etc.)
2. Promoting and streamlining strategic alliances for businesses and researchers with larger players or end-users
3. Providing mentorship and business planning assistance to small businesses to identify key technology benefits and attract private capital
4. Underwriting and disseminating “good science” research and public education into the long-term issues related to waste disposal, safety and regulations
5. Undertaking tort and legal reform which will provide developers greater immunity and protection once their products are Federally approved.

State governments and economic development bodies could assist small and large businesses link up in “ecosystem-like” neutral development environments by promoting leverage of nano-incubator and user facilities. By working with university and National Laboratory technology transfer organizations, they could facilitate simpler access to nanotechnology resources and training available in educational institutions, thereby stimulating new partnerships with entrepreneurs. Offering matching funds and other seed incentives to organizations pursuing Federal nanotechnology programs would provide further impetus for businesses and researchers to partner in commercialization ventures. Several progressive U.S. States have already initiated these next-generation technology partnerships.

2. Nanomanufacturing Industry Survey

2.1 Introduction

Nanomanufacturing is broadly defined as the controllable, large-scale manipulation of matter at the nanoscale (0.1 to 100 nanometers), to produce identical value-added components and devices. When the dimensional scales of materials and molecular systems approach the nanoscale, the conventional rules governing their behavior change significantly. The rapidly improving capability to manipulate matter at the atomic and molecular scales has already resulted in several first generation nanotechnology (popularly referred to as incremental or passive nanotechnology) applications and product enhancements. R&D efforts are underway internationally to develop active (second generation nanotechnology) sensors, actuators and communications devices with more complex, engineered 3D nanostructures, including the capability to link across biological interfaces. Over the next decade or two, these products are expected to be able to selectively sense, integrate and self-assemble at the nanoscale with other evolutionary atomic and molecular sub-assemblies to form third and fourth generation nanotechnology systems with visionary societal implications.

2.2 Survey Objectives

In 2005, under NSF direction, NCMS compiled and aggregated the representative strategic planning, technology development and commercialization trends, and documented the concerns of a broad cross-section of organizations involved in the rapidly evolving National Nanomanufacturing Industry. Essentially, NCMS attempted to determine whether surveyed organizations treat nanotechnology differently from any other generation of advanced science and technology.

A secondary goal of this largest industry-wide assessment effort conducted to date in North America was to examine the scalability of findings from a previous (Award # DMI-0305091) 2003 pilot survey of 81 organizations pursuing nanotechnology products [1].

The survey has developed a credible benchmark of the U.S. Nanomanufacturing Industry across multiple scales and strategy parameters – such as nanotechnology application markets, nanoproduct-specific industry profiles, and geographical/regional trends – with the objective of defining key areas of consensus and disagreement on the outlook for the U.S. Nanomanufacturing Industry in the decade ahead. Based on these survey findings, NCMS has recommended essential policy actions and technology strategies for accelerating and growing the industrial applications of nanotechnology in a responsible manner and maintaining the world leadership of the U.S.

It is the NCMS' and NSF's intention to make widely available the critical aggregate industry and business intelligence information to the stakeholders, including policymakers, investors, consumers, end-users, technology developers and academia, and thereby to offer a credible foundation for focusing attention, dialog and coordinated action regarding the myriad issues that surfaced in NCMS' research.

2.3 Definition of Nanotechnology

The NNI definition of nanotechnology was used to solicit survey participants, as it is the most recognized:

1. Research and technology development at the atomic, molecular or macromolecular levels, in the length scale of approximately 1-100 nanometer range

2. Creating and using structures, devices and systems that have novel properties and

functions because of their small and/or intermediate size

3. The ability to control or manipulate on the atomic scale
4. The ability to integrate those properties and functions into systems spanning from nano- to macroscopic scales.

3. Methodology

The online survey solicitation was launched electronically with the assistance of Small Times Media, Inc. (publishers of the industry's leading trade magazine) during February – August 2005 (Appendix A). Over 6,000 targeted senior executives in U.S. based manufacturing-related organizations known to Small Times, as well as NCMS manufacturing members/alliance organizations were invited to participate and provide assessments of their organization's current situation and future potential for nanomanufacturing, as well as its strengths and weaknesses. The NNI's definition of nanotechnology (Section 2) was used to qualify respondents, who were encouraged to candidly answer a fifteen-question electronic survey form addressing a variety of strategic issues associated with development and commercialization of new nanotechnology products.

The survey solicitation was not sent to non-manufacturing organizations such as industry financiers and business service providers (e.g. insurance companies, commercial realtors, conference organizers), legal advisors, regulators, or state incubator/economic development organizations, etc. all of which are not directly involved with the nano industry. However, several such organizations helped disseminate the survey and encouraged their manufacturing clients to participate. The following screenshot displays the Survey Welcome Page:

3.1 Additional Survey Questionnaire Dissemination

Additional survey publicity was conducted by the NSF sponsors and the principal investigator's talks at several nanotechnology industry gatherings, or through publications with the assistance of the following organizations:

- NSF NNIN and NSEC Grantees Conference 2004, Washington, DC
- NSF DMI Annual Grantees Conference 2005, Scottsdale, AZ
- Converging Technologies Bar Association, New York, NY
- ITB Nanoinvesting Forum 2005, Palm Springs, CA
- Marcus Evans 2005 Global Defense Institute Conference on Lightweight Materials for Defense Applications, Washington, DC
- NanoBio Nexus, San Diego, CA
- Risk Group LLC, Houston, TX
- Society of Manufacturing Engineers, Dearborn, MI
- Michigan Small Tech, Ann Arbor, MI.

3.2 Selected Interviews

To supplement the survey results, NCMS also conducted in-depth interviews with selected senior executives representing major manufacturing industry sectors pursuing nanomanufacturing developments. The outcomes of these interactions are included in this final report.

3.3 Response Rates and Metrics

The metric established by NSF for a successful survey project was 300 industry responses.

NCMS far exceeded the goal, garnering twice the envisioned number, which increases the certainty of survey data and findings. NCMS believes this was due in large part to the uniqueness of the project, its benchmarking goals as communicated to strategic and technology executives, and the assurance of confidentiality which was conveyed through the secure electronic access enabled by the Small Times Media portal.

A total of 602 responses were logged initially, of which 8 response datasets were eliminated as neither traceable names nor company affiliations were provided. This resulted in net 594 completed responses, representing a response rate of 10%, which is considered stellar for blind surveys.

Following additional information was logged on NCMS' host server:

- Survey completed and forwarded survey link to a colleague = 22 respondents
- Survey rejections (i.e. persons who opened the Survey Home Page and decided not to take it) = 66 respondents.

3.4 Ensuring Quality of Survey Data

NCMS engaged an expert survey design vendor, Ascendus Technologies, Inc., to develop a user-friendly and aesthetically pleasing online questionnaire. To elicit candid responses by executives, Ascendus incorporated an "instant gratification" incentive feature for displaying instantaneous dynamic preliminary (aggregate) data which would activate upon input or selection of a response option.

3.5 Aggregation and Reporting of Survey Results

In order to protect the confidentiality of the respondents, all results are reported in aggregate numbers only. Results are not reported where a single respondent provided 50% or more of the data for any specific category or question.

The data analyses were completed using Nano Data Explorer (NDE) Version 4.1, a novel graphical user interface software, based on Microsoft Excel, which was developed under NCMS subcontract by Ascendus Technologies to assist with conducting multi-variate and Boolean combinations of the very large and potentially rich data set of nearly 600 responses. The aggregate results are based on analyses of responses from 594 senior level executives with leadership, technology or strategic R&D responsibility in leading U.S. organizations.

Where appropriate, the 2005 Survey results are compared with industry data gathered in NCMS' 2003 Pilot Survey of 81 organizations [1].

4. Strategic Industry Indicators and Trends

4.1 Geographical Profile

The geographical distribution of 594 respondents, illustrated by U.S. Census regions in Figure 4-1, generally correlated well with the U.S. regions receiving the highest infusion of NNI funds and other private investments [2]. It agrees with the Small Times annual ranking of leading U.S. regions reporting the highest levels of commercial activity in nanotechnology [3]. Predictably, the Pacific regions represented the largest proportion (20.5%), considering that the electronics and semiconductor industry has been at the cutting edge of nanoscale science and engineering for several years, and the region is the single largest adopter of nanomanufacturing techniques. This was followed by respondents in the East North Central regions (18.7%), South Atlantic (15%), Mid-Atlantic (13%), New England (9.9%) and West South Central (9.6%).

4.2 Survey Highlights

Questions and the corresponding analyses are provided sequentially as taken by respondents in the survey.

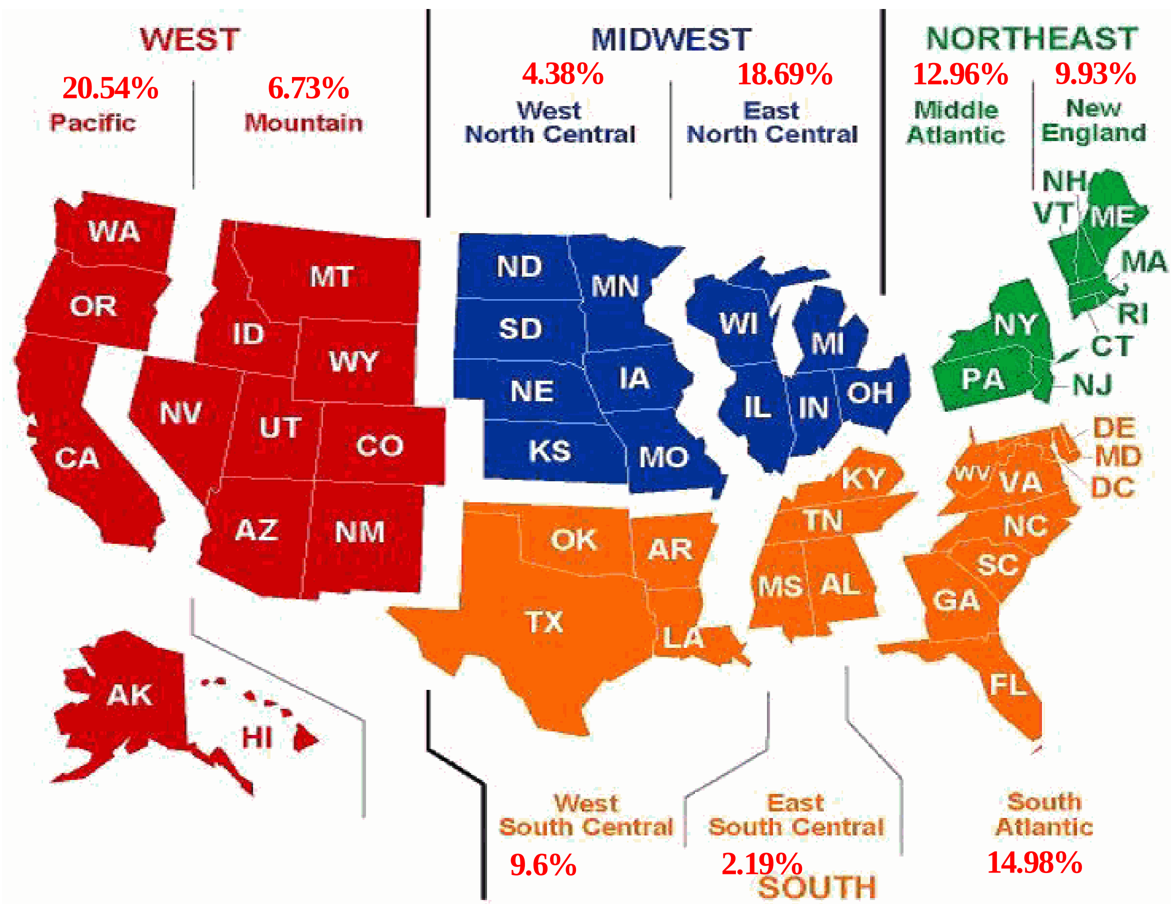


Figure 4-1. Geographical Distribution of 594 Respondents Corresponds Closely with Regions Receiving Major Public Investments in Nanotechnology

4.2.1 Major Players in Nanomanufacturing

About half of the 594 respondents indicated their organizations were directly involved in nanomanufacturing developments, either as end-users (OEMs), manufacturer/integrators or component suppliers.

As illustrated in the screenshot, respondents were asked to select from a tiered list their organization's primary or envisioned role in the nanomanufacturing value chain.

Many organizations and entities are involved directly in the development and manufacturing commercialization of nanotechnology, and these numbers are growing rapidly in the U.S.

4.2.1.1 Aggregate Results

Nearly half of the survey respondents indicated their organizations are directly involved in nanomanufacturing (Figure 4-2). This group (totaling 43%) was comprised of manufacturers/integrators and component suppliers/vendors of nanotechnology products and equipment. This was followed by university-based developers (19%), service suppliers (15%) and researchers based in private or government R&D laboratories (12%).

Respondents were broken down into the following categories of Organization types:

- 8.92% End-users or consumers of products incorporating nanotechnology (e.g. executives from the aerospace, automotive, healthcare and transportation industry OEMs)
- 30.04% Manufacturer/integrator of nanotechnology components (e.g. Tier 1 assembly or sub-assembly suppliers and equipment suppliers)
- 13.47% Component supplier/vendors of nanotechnology products (i.e. nanomanufacturers)
- 15.32% Service suppliers (i.e. providers of specialty services in nanomanufacturing such as engineering, consulting and training)

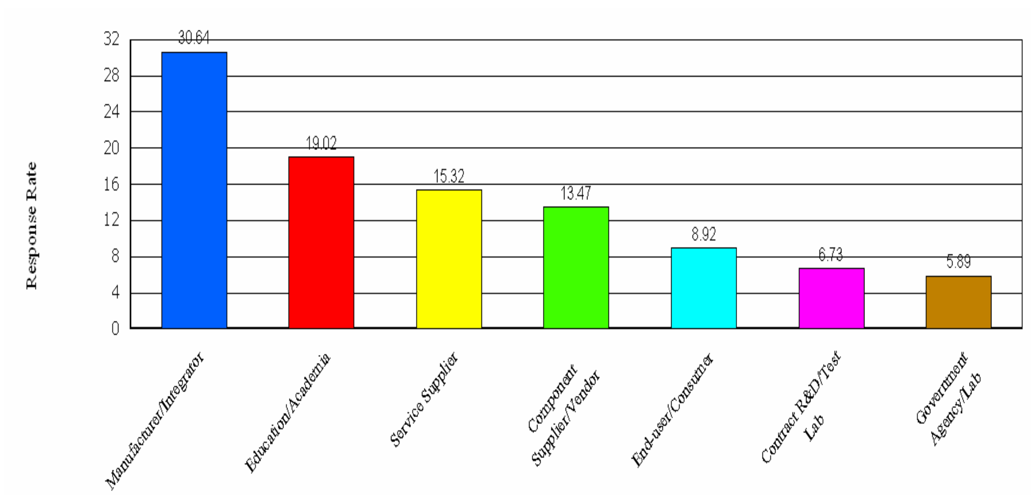


Figure 4-2. Respondents' Roles in the U.S. Nanomanufacturing Value-Chain

- 6.73% Contract R&D or test laboratories (i.e. private sector laboratories and research vendors)
- 19.02% Education and academia
- 5.89% Government agencies or laboratories.

4.2.2 Nanomanufacturing Application Markets

Nanotechnology developments are being targeted for use in diverse industry sectors – the top application markets for nanotechnology products are:

- *52% Equipment, Logistics and Distribution*
- *46% Electronics and Semiconductors*
- *46% Computing, Information Technology (IT) and Telecommunications*
- *38% Aerospace*
- *34% Automotive*
- *33 % Chemicals and Process Industries*

Respondents were asked to indicate all industry sector(s) their organization is targeting with new nanomanufactured products. The list of 16 available options was consolidated as logically as possible so as to make it easy for respondents to select and "click" on key industry categories without viewing a more extensive list of narrower options.

4.2.2.1 Results

Nanotechnology developments are being targeted for use in diverse industry sectors as depicted in Figure 4-3.

Results are compared with the information reported in the databox below from the 2003 NCMS-NSF Survey [1].

<u>2003</u>: Top Seven End Uses were:

35%	Electronics
33%	Coatings
32%	Devices and sensors
19%	Automotive applications
18%	Raw materials supply
15%	Biotechnology/biomedical
13%	Polymers and petrochemicals

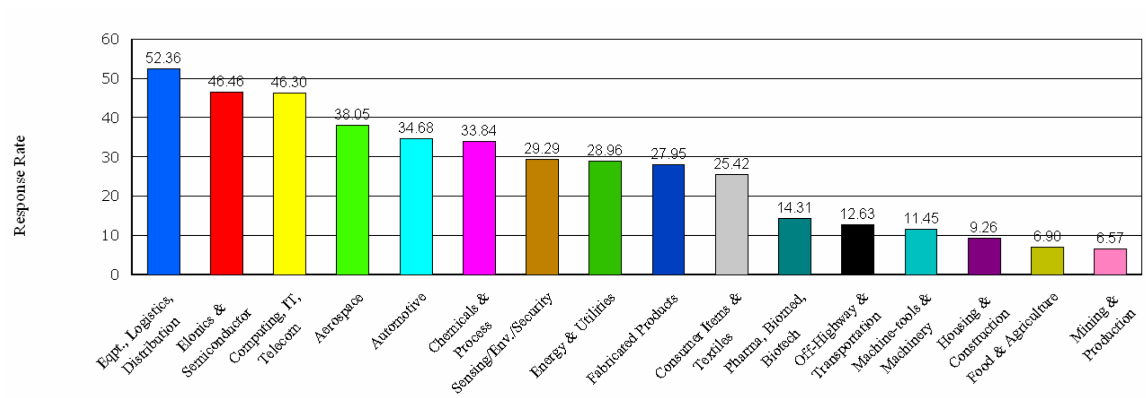
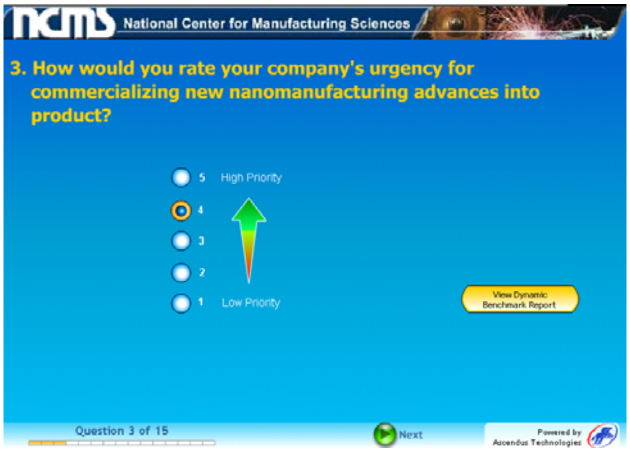


Figure 4-3. Nanotechnology Developments Being Targeted for Use in Diverse Industry Sectors – 2005 Data

4.2.3 Corporate Urgency

Management attitudes are changing – medium and large organizations (50 or more staff) place a higher priority on commercialization of nanotechnology.



This question was intended to assess the industry insiders' recognition and awareness of the changes in corporate attitudes towards nanomanufacturing. In other words, "Was the commercialization of nanotechnology important to their organization?"

For effectively commercializing nanotechnology and harnessing the many unique benefits it offers, it is widely recognized that all sectors and tiers of industry will have to radically change management approaches, business models and corporate strategies. NCMS asked industry insiders to rate how their organizations were coping with changes towards the "nanofuture." Selections ranged from 1 – Low Priority to 5 – High Priority.

4.2.3.1 Results

By Aggregate

52% of the aggregate respondents stated nanomanufacturing is considered a high priority for development in their organizations, while about 20% indicated low priority (dominated by organizations in East North Central and New England regions) (Figure 4-4).

By Organization Role

Specifically, 62% component vendors/suppliers, 57% manufacturers/integrators, 56% contract R&D labs and 52% end-users reported their organizations place high priority on nanotechnology developments.

45% respondents from government labs, 30% from the service sector, and 32% respondents from academia stated commercialization received medium priority.

By Organization Size

At least two-thirds of respondents from organizations with 50-100 staff in nanotechnology and nearly 60% of the large players in nanotechnology (i.e. corporations with over 100 staff) indicated that their organizations place high priority on commercialization of nanotechnology; only about 10% of these large organizations indicated low priority. Similar patterns were found in responses of smaller and medium size organizations working with nanotechnology products (i.e. 21-50 staff) as shown in Figure 4-5.

However, only 40% of executives from the smallest organizations (less than 10 staff), indicated their corporations place a high priority on commercialization of nanotechnology – many of these companies are either specialized consultants, IP-holding organizations or early stage start-ups and spin-offs from academia with limited resources and physical assets for pursuing nanotechnology. This pattern is illustrated in Figure 4-6.

2003: Nearly two-thirds (63%) of 81 executives felt that their business and market(s) were changing rapidly, thereby impacting their organization's strategy. Less than 10% felt that change was slow in their business.

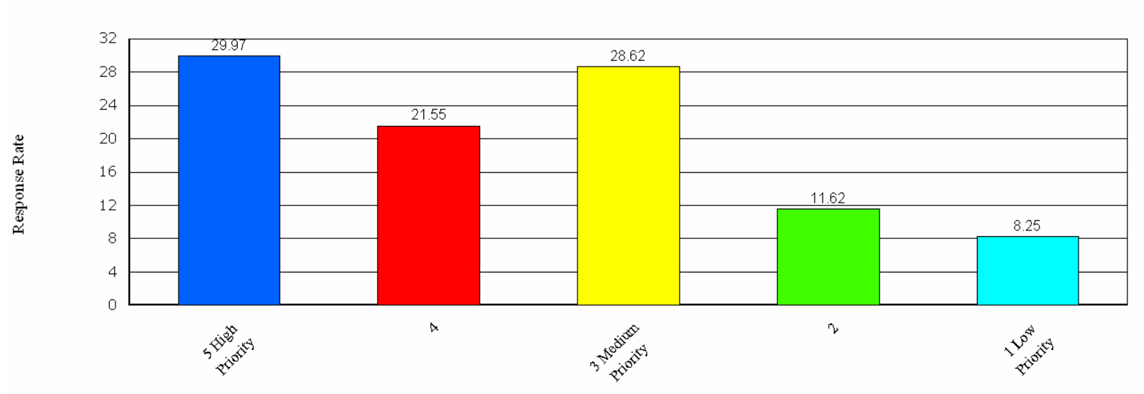


Figure 4-4. Half of the Executives Indicated Higher Levels of Corporate Urgency Towards Nanomanufacturing

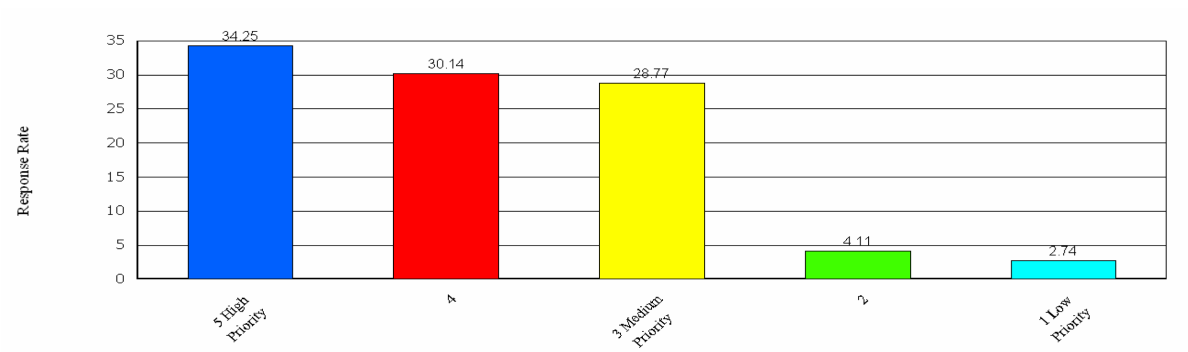


Figure 4-5. Nanotechnology Receives Higher Management Priority in Medium and Large-Size Organizations

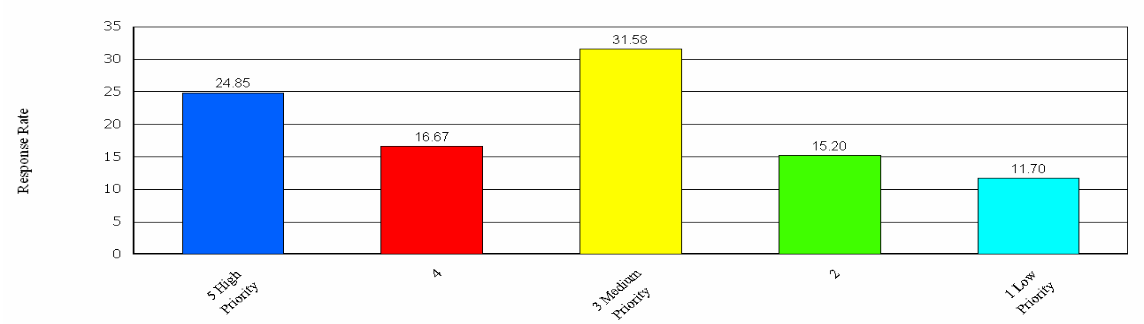


Figure 4-6. Lower Levels of Corporate Urgency were Indicated by Small Organizations (less than 10 staff)

4.2.4 Change Management

Majority of medium and large nanotechnology organizations (50 staff or higher) were coping relatively well with adopting new commercialization strategies and technology management approaches, but smaller organizations reported greater difficulty in coping with market and business changes.

The survey intended to assess how well respondents' organizations were transitioning and re-aligning their resources to address the myriad potentially disruptive issues (e.g. market focus, technology/product portfolio, investments, partnering, etc.) concerning their activities in the commercialization of nanotechnology. The query was aimed at gauging executives' assessment of how their organizations were making technology and business improvements and finding effective ways for managing the process of change towards the "nanofuture."

Selections ranged from 1 – Coping Poorly to 5 – Coping Very Well.

It is widely recognized that to effectively commercialize and harness the potentially disruptive benefits of nanotechnology, a large part of industry across many sectors will have to radically change business models, management approaches and corporate strategies. For example, these changes may involve:

- Building stronger relationships with academic researchers, the National Laboratories and other Centers of Excellence in nanotechnology to ensure the efficient transfer of nanotechnology research into mainstream products.
- Fundamental changes in corporate strategy – commercial entities may need to broaden their perspective of "what business are we in?" relative to the fundamentally multi-disciplinary aspects of nanotechnology, the need for broader access to IP, and the potential impact on a range of societal and environmental scales.

4.2.4.1 Results

By Aggregate

At least half (46%) of the aggregate respondents across the nanomanufacturing value-chains stated their organizations were coping relatively well with strategy, resource and market changes. However, nearly a fifth of the respondents indicated serious concerns. This aggregate profile is unchanged over the 2003 survey conducted by NCMS when a similar aggregate number was reported. About 25% of the respondents from the East North Central Region and 19% from the West North Central Region stated their organizations are coping poorly with the commercialization of nanotechnology (Figure 4-7).

By Organization Size

Larger nanotechnology organizations handle change better than smaller ones, as indicated below by two-thirds of the respondents from large (over 100 staff) nanotechnology firms (Figure 4-8). It was observed that the larger the organization (e.g. 50 staff or greater), the better it performed in coping with change management issues. As organization size decreased, the proportions of organizations indicating difficulty in coping with change increased. Smaller organizations appear to have the greatest difficulty in coping with market and business changes. Thus, while size and leanness are considered virtues (equated to agility) in conventional manufacturing industries, this may not hold true in case of the nanomanufacturing industry, where small companies invest their scarce manpower, infrastructure and nanotechnology resources in development of specialty products, often for niche or undeveloped markets. Therefore, these entities have limited capability to cope with major change in product focus, market sectors or customer requirements (Figure 4-9).

2003: These 2005 statistics for small organizations were similar to those recorded as a composite in the 2003 Survey when 46% of respondents felt their organizations were coping well with strategy changes (e.g. technology/product portfolio, investments, market focus, etc.), and only 2% felt they were coping poorly with developing and implementing strategies for new nanotechnology products.

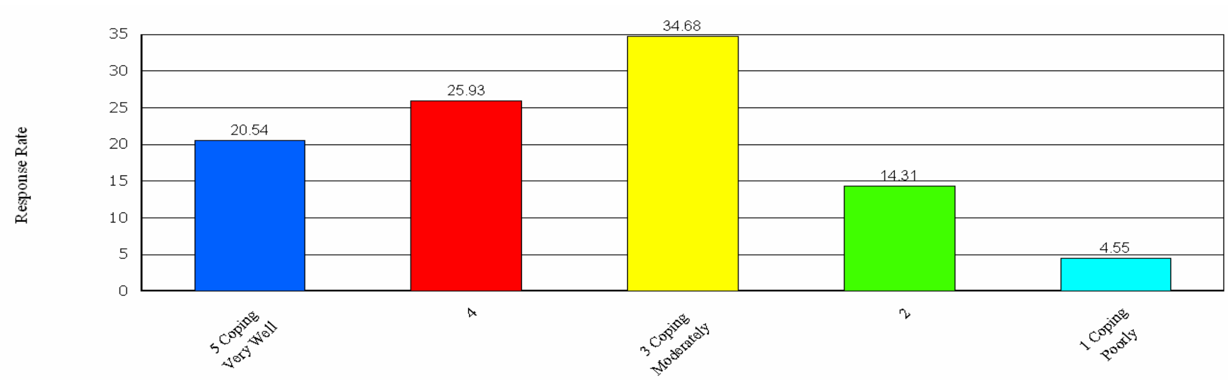


Figure 4-7. Majority of Nanotechnology Organizations are Coping Well in Commercialization of Nanotechnology

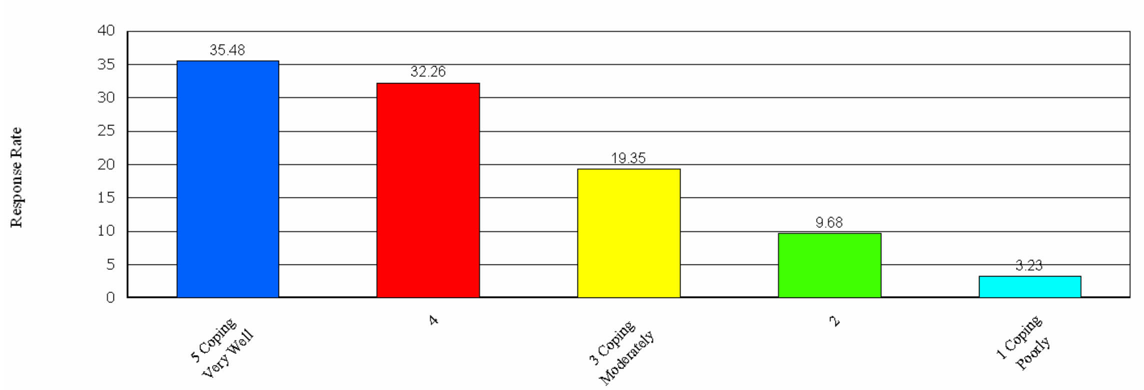


Figure 4-8. Larger Nanotechnology Organizations (>100 staff) Handle Change Management Better

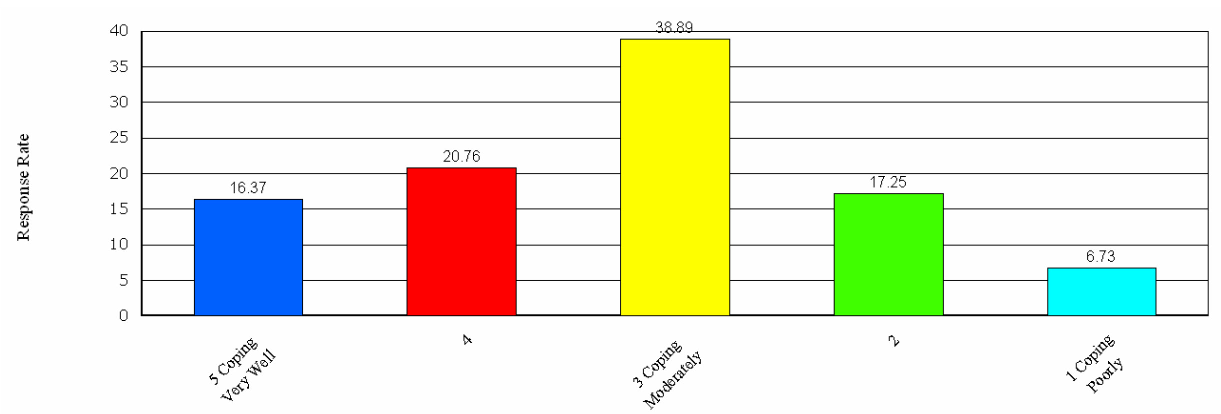
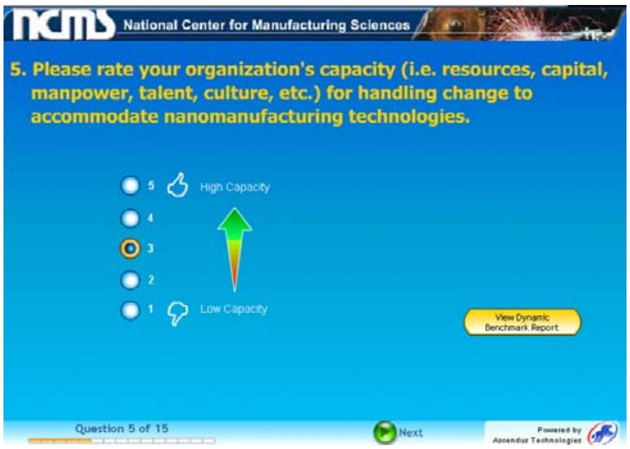


Figure 4-9. Small Companies (< 10 staff) Have Greater Difficulty with Change Management

4.2.5 Organizational Capacity

Increasing numbers of senior executives in the conventional U.S. Manufacturing Industry have begun examining the potential of nanotechnology to take their organizations into new growth phases, product directions and markets, and are translating this interest into R&D partnerships, procurement or acquisition of new nanotechnology development resources.



Respondents were asked for a qualitative assessment of their organization's internal capacity, involving resources, access to capital, manpower, talent and corporate culture – again, this was intended to help corroborate answers to previous questions.

Selection options ranged from 1 – Low Capacity to 5 – High Capacity.

4.2.5.1 Results

By Aggregate

In aggregate, about 70% of all respondents reported medium to high levels of organizational capacity to pursue nanomanufacturing. However, nearly 30% respondents reported low capacity. This is regarded as a significant improvement from the 2003 survey, when over 50% of respondents (based on a smaller sample size of 81) felt their organizations did not possess sufficient internal capacity to pursue nanomanofacturing developments. The improved aggregate trend may be attributed to the greater awareness levels about nanotechnology within corporations, senior management and shareholders, raised by the NNI's significant investments of public funds in R&D as well as the outreach efforts and endorsements by the Nation's leadership. As a result, increasing numbers of corporate strategy planners and senior executives in the conventional U.S. Manufacturing Industry have begun examining the potential of nanotechnology to take their organizations into new growth phases, product directions and markets, and are then translating this interest into partnerships, procurement or acquisition of new nanotechnology development resources. This trend is likely to accelerate in the coming decade.

The highest proportions of respondents expressing concerns with organizational capacity (low) were found in the Mountain (35%), East North Central (31%) and East South Central States (30%).

By Organization Size

Over 85% of the large organizations (>100 staff) indicated high levels of organizational capacity for nanomanufacturing (Figure 4-10). As expected, the smallest organizations expressed the greatest levels of concern about their internal capacity for nanomanufacturing (Figure 4-11). Larger companies and start-up companies with strong alliances e.g. with angel investors and venture capital (VC), universities, suppliers or National Labs fared better and thus, developed greater capacity for taking risks in nanotechnology-focused developments.

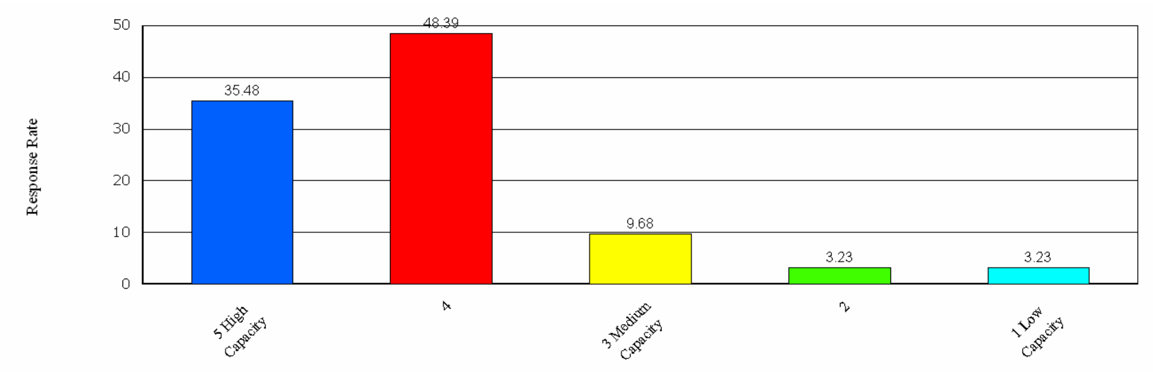


Figure 4-10. Large Businesses (>100 staff) Indicated Higher Organizational Capacity for Nanotechnology Developments

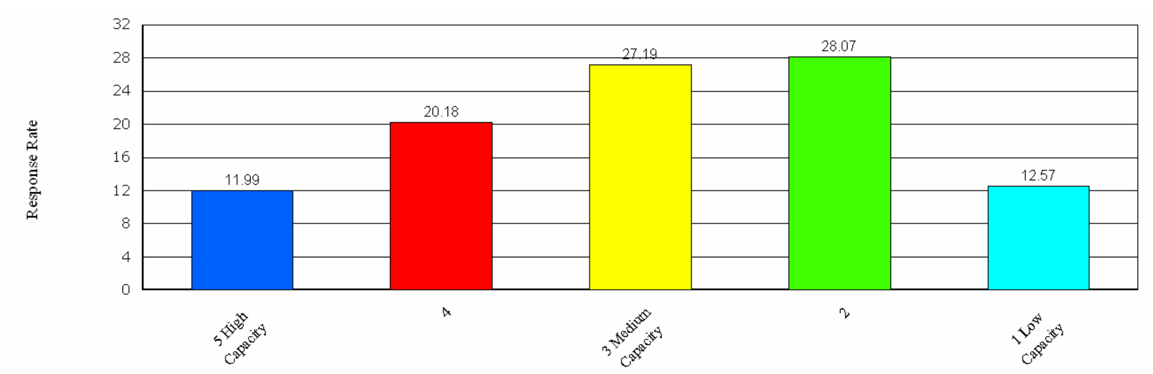


Figure 4-11. Majority of Small Organizations (< 10 staff) Have Significantly Lower Organizational Capacity in Nanotechnology Development

4.2.6 Internal Infrastructure

Nanotechnology infrastructure is unevenly distributed across the U.S. and in its utilization by various industry sectors – additional specialty tools and targeted facility investments are needed in the private sector.

This question was directed for industry insiders to provide candid assessments of their organization's infrastructure for nanomanufacturing, in terms of laboratory space and facilities, processing equipment, test and diagnostics capability, etc. Nanotechnology developments are typically undertaken in clean rooms, similar to those used in the development and manufacturing of microelectronics and semiconductor devices. Ultra-clean rooms and other facilities used in the U.S. for nanotechnology developments are largely derivatives of the micro electro-mechanical systems (MEMS) or digital electronics industry. They are typified by large equipment and logistics footprints, capital-intensive, high-security facilities, a range of fabrication, metrology and characterization equipment, strict environmental controls, as well as continuous monitoring and sensing/ detection apparatus – all of which are required for the manufacture and verification of geometrically precise products in high volume. These ultra-clean requirements therefore, contribute in a large way to the high cost of processing of nanotechnology products.

In posing this question, NCMS and the NSF were interested in determining how respondents regard the adequacy of critical internal hardware-related resources. Many aspects of nanoscale manufacturing require some form of clean room technology – either as full-scale Class 1,000 facilities or as more compact "table top" scale facilities, which would depend on the particular process, industry or application being pursued.

Selection options ranged from 1 – Significantly Lacking to 5 – Plentiful.

4.2.6.1 Results

By Aggregate

Figure 4-12 shows that the respondents in aggregate, were nearly equally divided in rating the adequacy of their available infrastructure for undertaking nanomanufacturing developments:

- 39% selected Plentiful
- 30% selected Adequate
- 31% selected Inadequate (with 9% selecting Significantly Lacking)

Lower satisfaction numbers were reported in our 2003 Survey project. In the last few years (thanks to NNI programs and facility investments in academia, small businesses and the National Laboratories, leveraged with private sector investments), the expansion and availability of nanotechnology infrastructure equipment resources has been very broad and substantial, across nearly all industry/application sectors. Highest levels of satisfaction with nanotechnology infrastructure were expressed by respondents from the New England (83%), South Atlantic (81%) and West North Central (72%) regions. New infrastructure investments could stimulate commercialization activity in the Pacific, Mountain, West North Central, East North Central and East South Central Regions where at least 30% respondents expressed dissatisfaction with availability of infrastructure. The reason for including the Pacific region in this list is that much nanotechnology infrastructure is tied up in the large semiconductor manufacturers and suppliers.

By Industry Sector/Application Markets

One-fifth of all organizations expressed inadequate infrastructure. The response profiles for the vast majority of the nanotechnology application markets resemble Figure 4-13 for the pharmaceutical, biomedical and biotechnology industry sector.

The exception profile was the metals, mining and raw materials production industry sector where nearly 90% respondents indicated satisfaction with their available internal infrastructure (Figure 4-14). This corroborates the fact that some of the earliest commercial applications of nanotechnology have been for consumer products, and cosmetics, all of which use raw materials from mineral products, indicating that these manufacturing suppliers have invested in adequate infrastructure for processing, measurement and characterization of nanotechnology products.

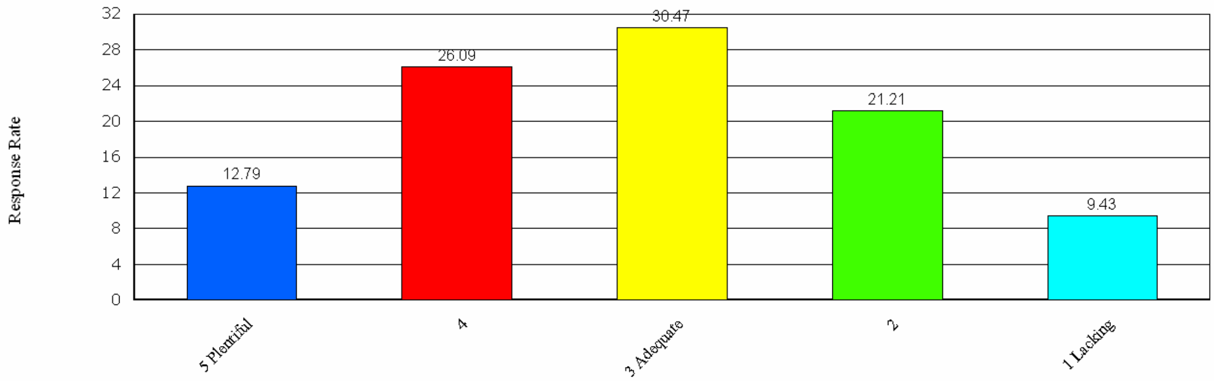


Figure 4-12. Aggregate Industry Responses Indicate Significant Dissatisfaction with Nanotech Infrastructure

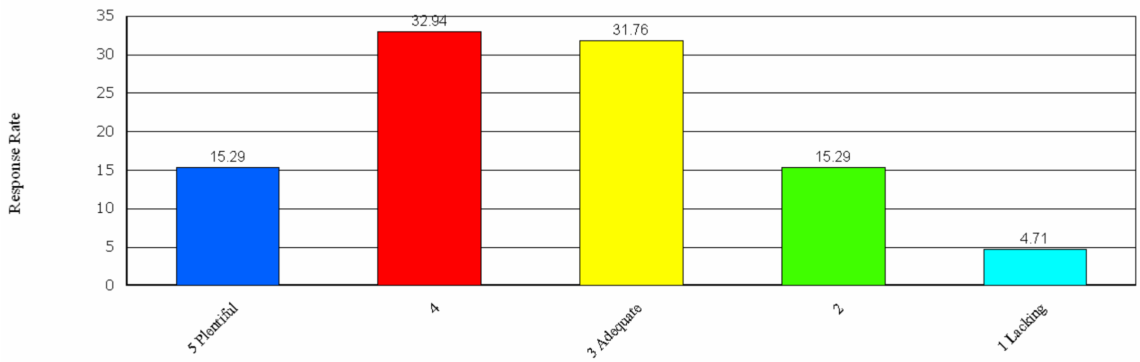


Figure 4-13. Pharmaceutical, Biomedical and Biotechnology Industry Assessments of Internal Infrastructure

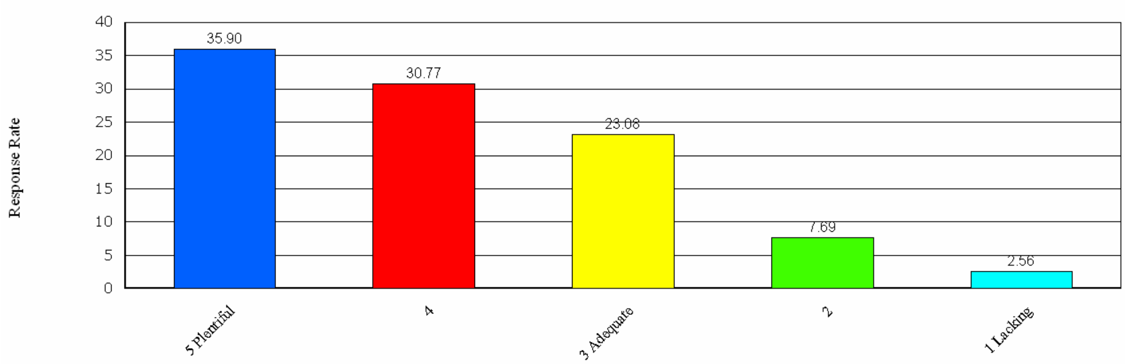


Figure 4-14. The Mining and Raw Materials Production Industry's Assessment of Internal Infrastructure

By Organization Role

When the data was examined by organizational role in nanotechnology value chains, over 70% of respondents in government labs indicated adequate to plentiful infrastructure; however, 17% of end-users, 28% of manufacturer/ integrators and 19% academic respondents stated their infrastructure was significantly lacking. This indicates that additional specialist tools and facilities are needed for manufacturing, test, assembly and inspection/verification/characterization of nanotechnology products and processes.

By Organization Size

As expected, the larger the organization, the larger the proportion of respondents indicating adequate to plentiful infrastructure for nanotechnology development. Nearly all organizational size categories (i.e. staff numbering 11-100 or larger), indicated they possess adequate to plentiful infrastructure. While 30% of the smallest entities (less than 10 staff) indicated adequate to plentiful infrastructure, over 40% of respondents from such small companies stated they lacked critical infrastructure for nanomanufacturing (Figure 4-15). NCMS believes many of these small organizations are the newer, knowledge-based businesses (typically, university faculty-led start-ups or new entrepreneurs), that require access to specialized facilities and equipment. Many such organizations are known to be pursuing State, Federal or private funds, as a means of acquiring new infrastructure and equipment.

By Region

Across all nine U.S. geographical regions, an average 25% of the respondents indicated inadequacy of infrastructure for pursuing nanomanufacturing – this metric went as high as 37% for respondents in the Great Lakes or East North Central States (IL, IN, MI, OH, WI), and 35% for respondents from the Pacific region states (AK, CA, OR, WA). Figure 4-16 illustrates representative responses on a geographical scale.

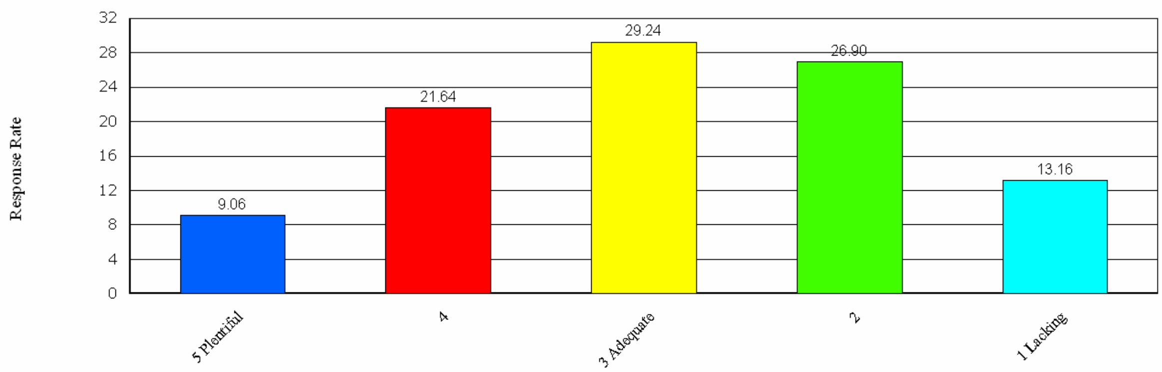


Figure 4-15. Internal Infrastructure Deficiencies are Significant in Majority of Small Nanotechnology Organizations

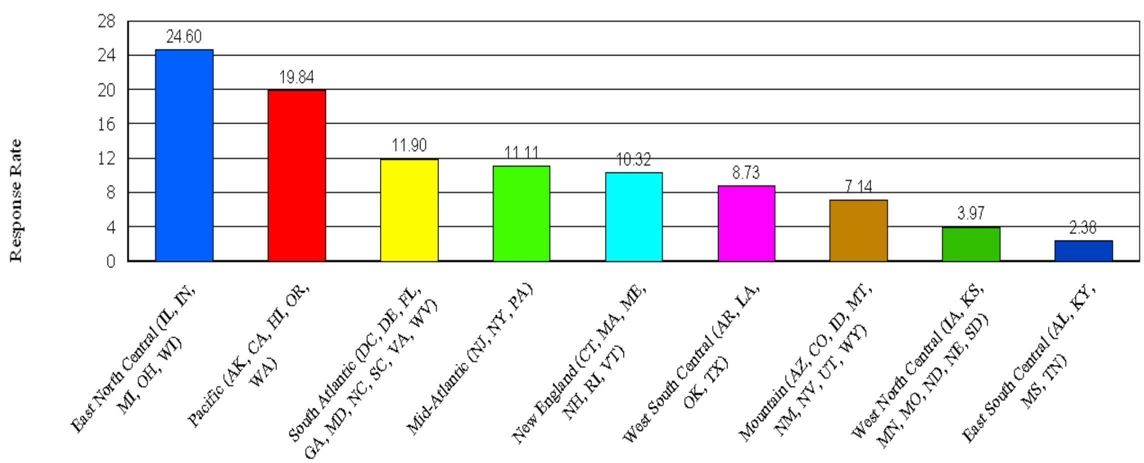
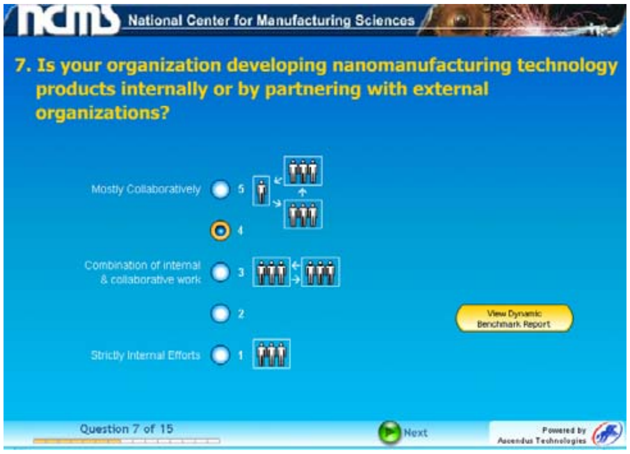


Figure 4-16. Organizations in the Great Lakes and Pacific Regions Indicated Highest Levels of Inadequacy of Internal Infrastructure for Nanomanufacturing

4.2.7 Collaborative Development

Collaborative developments, while on an increasing trend, are highly product specific in the U.S. Nanotechnology Industry.



This question was posed in order to determine how much product – and technology-specific partnering is occurring in the commercialization of nanotechnology, amongst end-users/customers, suppliers, academia, National Labs, trade groups, and other entities.

Organizations typically collaborate or join strategic alliances in order to achieve specific business-related goals and outcomes that may be part of their corporate strategy regarding nanotechnology products. Examples of such alliances vary from research consortia to product joint ventures to supplier networks. An organization's role within a nanotechnology value chain largely determines whether it engages in "market pull" activities or "technology push" activities [4].

Nanotechnology is inherently a multi-disciplinary field, involving the convergence of laws and practices from chemistry, physics, materials science and electricity at the minimum at the R&D level, but these rapidly become far more complex and interactive when considered at the engineering and manufacturing levels. Consequently, the business and technological implications of the newer nanotechnology products in development (such as active, 3D nanostructures and devices) have the potential to both, transform and affect all aspects of society and the environment.

Given the current economic reality of risk reduction and investors/management's (Wall Street, too) emphases on short-term performance and cost-containment and asset reduction, few organizations possess the extensive resources and facilities (or the patience) to develop nanotechnology products on their own. These drivers have to be balanced with some key inhibitors to collaboration in the nanotechnology industry, such as the corporation's desire to dominate and expand its (IP) portfolio, as well as perform equitable valuation of new IP on collaboratively developed products and processes that may not have well-defined markets or growth projections.

NCMS believes that the successful commercial exploitation of advanced nanotechnology products requires unprecedented levels of collaboration (both, vertical and horizontal) across many different realms in order to adequately address the inherent complexities associated with the lifecycles of such products. Bottom-up processes such as molecular self-assembly and self-replicating nanotechnology processes are regarded as some of the most challenging areas for longer-term development. Convergence products which simultaneously incorporate nanotechnology, biotechnology, IT, and cognitive science commonly referred to as NBIC, represent another highly complex class of new products, thus, providing the long-term impetus for new forms of partnerships, co-development and information sharing, across all categories of stakeholders.

Besides polling the respondents on the extent of partnering their organizations were involved with, NCMS asked them in the next question to indicate their organization's specific drivers for partnering.

4.2.7.1 Results

By Aggregate

In aggregate, over three-quarters of all survey respondents indicated their organizations were involved in collaborative arrangements with external organizations, while about 20% are working internally on nanotechnology developments (Figure 4-17). The highest percentages of respondents pursuing strictly internal developments are in the Mountain (34%), West South Central (29%) and Pacific (26%) regions.

While the aggregate numbers appear unchanged from the 2003 survey of 81 organizations, NCMS believes that the levels of collaboration are highly product specific in the nanotechnology industry.

An attempt was made to study correlations between nanotechnology application markets and level of collaboration, but did not yield significant trends or findings that could be generalized – the survey questionnaire was not designed with the granularity to investigate this further. Slightly higher proportions of respondents in organizations targeting the food and agriculture markets (40%), and the pharma/biomedical/biotechnology markets (28%) appear to be engaged in external collaborations.

By Organization Role

Nearly two-thirds of all OEMs (end-users) indicated they are involved in collaborative nanotechnology product developments, while about 20% are pursuing developments internally. Over 30% of manufacturers and nanotech suppliers also stated they are pursuing nanomanufacturing largely internally, with little external collaboration. This trend indicates the high levels of sensitivity with which organizations view collaboration in this industry and in addressing proprietary developments (Figure 4-18). However, the respondents from government laboratories indicated the highest levels of external collaborations.

By Organization Size

While higher levels of collaboration were evident across all organizational role types and staffing sizes, nearly 20% of respondents from large (>100 staff) organizations indicated their nanotechnology developments are by "strictly internal" efforts, indicating the highly proprietary nature of their developments; this also confirms the availability of adequate to plentiful internal resources and infrastructure facilities to these organizations (Figure 4-19).

Nearly 75% of respondents from the smallest (< 10 staff) organizations indicated they rely on external collaborations for pursuing nanotechnology products – only 12% reported nanotechnology developments were done entirely with internal resources (Figure 4-20).

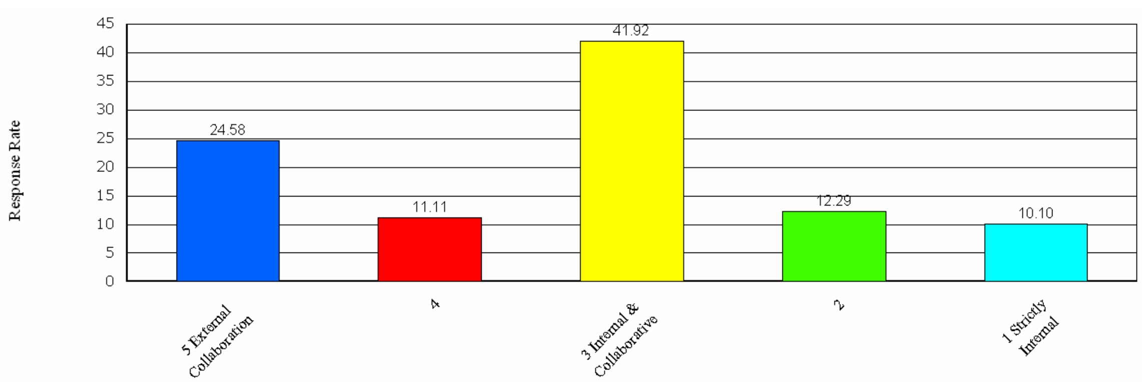


Figure 4-17. Majority of Organizations Involved in Collaborative Nanotechnology Developments

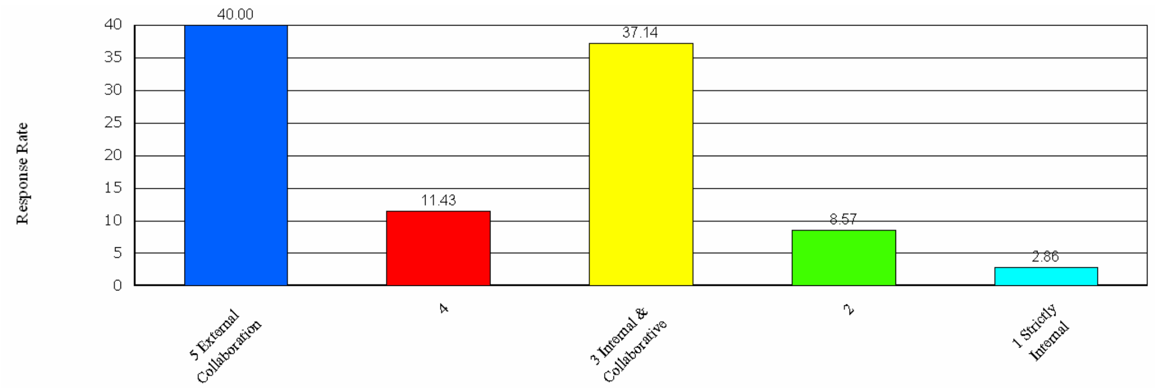


Figure 4-18. Collaboration Profiles in Nanotechnology at U.S. Government Organizations

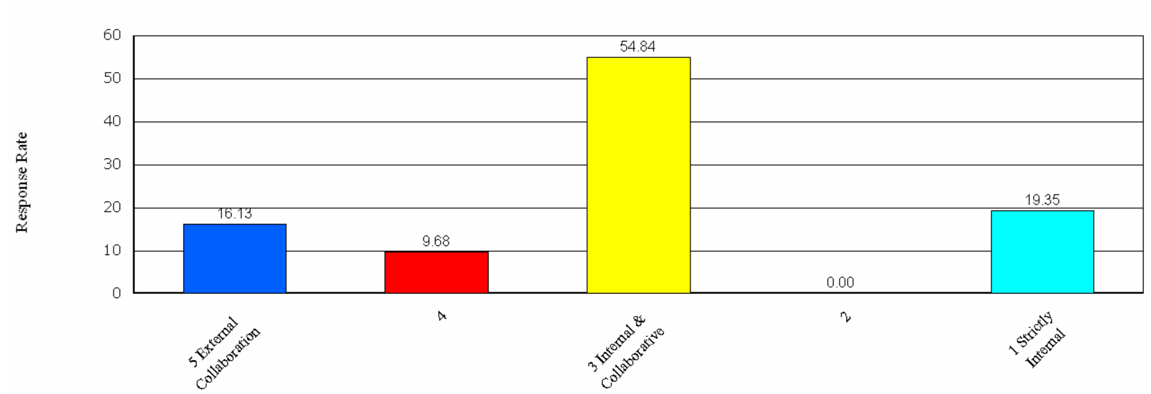


Figure 4-19. Collaborative Development Profiles for Large Nanotechnology Organizations

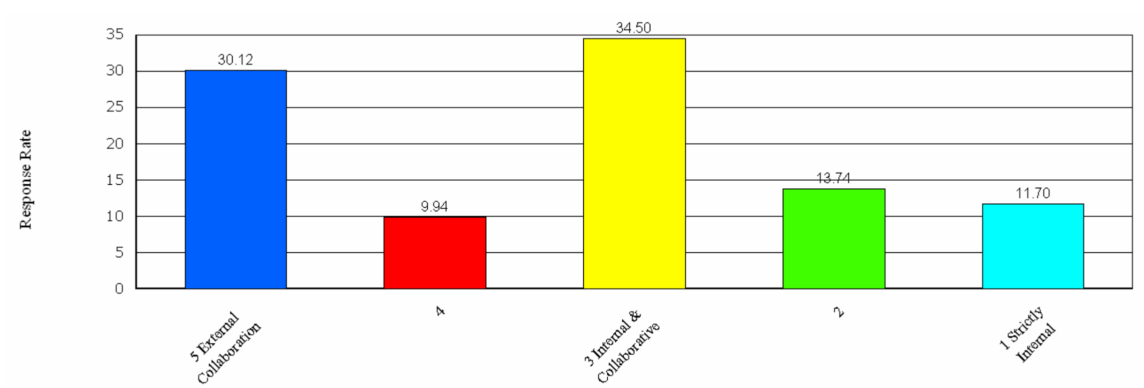


Figure 4-20. Higher Proportion of Small Organizations Involved in Nanotechnology Collaborations

4.2.8 Drivers for Partnering

Nanotechnology organizations were motivated to partner and collaborate for three main goals: to gain access to new markets and/or distribution channels; to better assess end-users' needs in order to co-develop focused products and solutions incorporating nanotechnology advances; or (in the case of longer-term nanotechnology research) to leverage resources and reduce development risks.

Organizations working in nanotechnology are driven to partner and collaborate by goals such as: access to new (or established) markets via new distribution channels; assess end-users' technical needs in order to co-develop focused products and solutions incorporating nanotechnology advances; or (often in the case of longer-term nanotechnology research) to leverage limited resources and reduce development risks.

Survey respondents were asked to select which one of the following three objectives primarily drives their organization to collaborate or partner externally in nanotechnology:

A. Partnering to access global markets
B. Partnering to access new technology
C. Partnering to access capital equipment

4.2.8.1 Results

By Aggregate

In aggregate, respondents expressed nearly equal preferences on what motivates their organizations to collaborate in nanotechnology. However, the breakdown of responses was more interesting and trends more apparent when the data was analyzed by each driver, company size and other interacting factors. Figure 4-21 illustrates these aggregate key drivers for all respondent organizations.

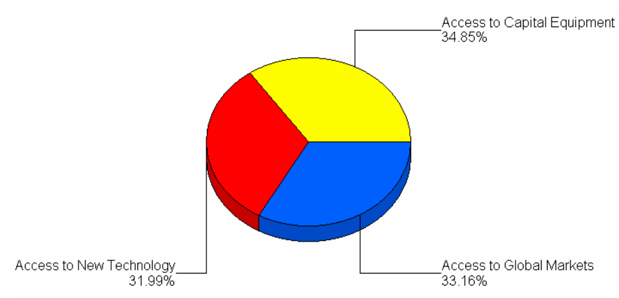


Figure 4-21. Respondents Expressed Equal Preferences on Partnering Drivers

Generally, organizations that indicated they are already marketing nanotechnology products, or expect to commercialize within 1-3 years were more driven to collaborate in order to gain access to global markets.

Organizations that had longer commercialization timelines (3-5 years or longer than 5 years) were more likely to select options (B) or (C).

In NCMS' experience, the larger, established conventional manufacturing companies and end-users tend to look for partners with intellectual assets who could help them develop nanotechnology products or enhance existing products, e.g. the automotive, aerospace, off-highway/ transportation and machine-tool manufacturers. Such organizations often have a department dedicated to organizing external collaborations, or technology acquisitions/licensing, and thereby accelerating the introduction of nanotechnology into new products.

The smaller manufacturers and R&D laboratories, seek new customers, end-users and other tier organizations who want to evaluate and use their nanotechnology products, such as nanoparticulate powders, nanotubes, nanocoatings and other highly engineered precursors.

A. Partnering to Access Global Markets

Respondents who picked this option also indicated the following top six application markets their organizations are pursuing in nanomanufacturing:

- Nanotechnology Equipment, Logistics and Distribution
- Electronics and Semiconductors
- Computing, IT and Telecommunications
- Aerospace
- Automotive
- Chemicals and Process

This partnering driver was also selected by a higher number of respondents from organizations commercializing nanotechnology for machine-tool and machinery applications, as well as energy and utilities application markets.

Organizations are partnering to access global markets in the following top five areas of nanotechnology product development:

1. Semiconductors, nanowires, lithography and printing products
2. Nanostructures, nanotubes and self-assembly
3. Coatings, paints, thin films and nanoparticles
4. Environmental sensing and remediation
5. Defense applications and protection gear

Access to global markets also appears to be the main driver for the majority (45%) of large company respondents (>100 staff) in the NCMS survey, as well as a significant number of medium-sized organizations (21-100 staff) which indicated they partnered primarily to pursue global markets in nanomanufacturing (Figure 4-22).

The top five barriers and challenges to nanomanufacturing shared by these respondents were:

1. High cost of processing
2. Lack of investment capital
3. Perception that nanotechnology products take a long time to market
4. Process scalability
5. IP issues

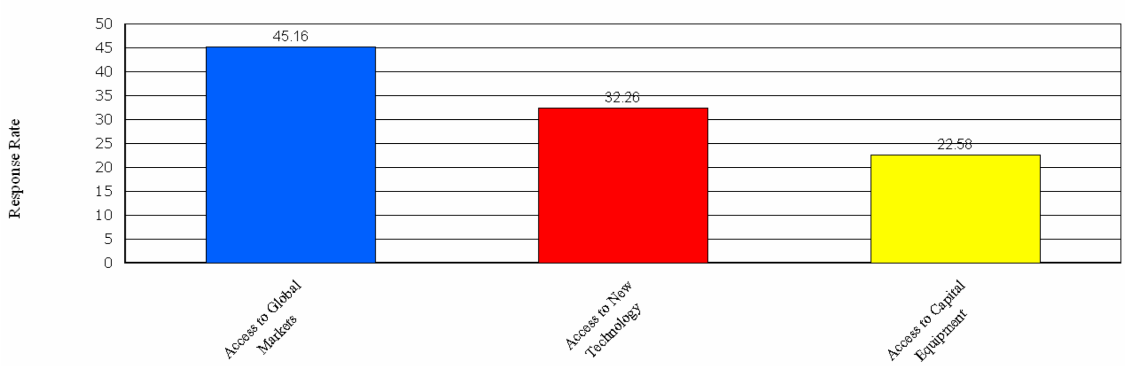


Figure 4-22. Partnering Drivers for Large Nanotechnology Organizations

B. Partnering to Access New Technology

Respondents who picked this option also indicated the following top six nanotechnology application markets their organizations are pursuing:

- Computing, IT and Telecommunications
- Nanotechnology Equipment, Logistics and Distribution
- Electronics and Semiconductors
- Sensing, Environmental and Security
- Aerospace
- Chemicals and Process

These organizations are partnering to access new technology in the following top five areas of nanotechnology product development:

1. Semiconductors, nanowires, lithography and printing products
2. Coatings, paints, thin films and nanoparticulates
3. Drug delivery systems, diagnostics and medical implants
4. Nano-biotechnology, nanofluidics and tissue engineering
5. Nanostructures, nanotubes and self-assembly

Figure 4-23 provides a detailed list of nanoproducts being collaboratively pursued.

These respondents also ranked the following five top barriers they face in nanomanufacturing commercialization efforts:

1. Perception that nanotechnology products take a long time to market
2. High cost of processing
3. IP issues
4. Lack of investment capital
5. Process scalability

Figure 4-24 is the profile of respondents' organizational roles for medium-sized (21-50 staff) nanotechnology businesses that indicated they engaged in collaborations and partnerships in order to access new technology.

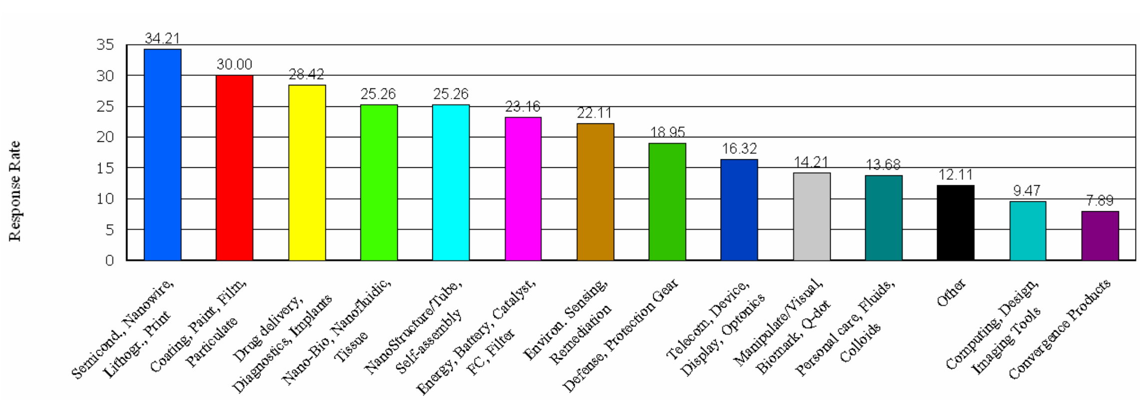


Figure 4-23. Nanotechnology Product Applications Pursued by Organizations Partnering for Access to New Technology

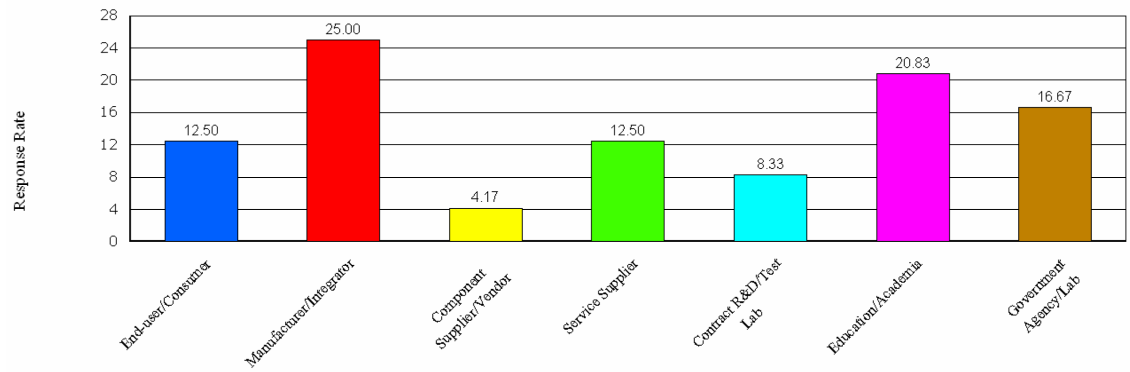


Figure 4-24. Roles of Medium-Size Nanotech Organizations Partnering for Access to New Technology

C. Partnering to Access Capital Equipment

The survey data indicated that U.S. organizations are partnering to access new equipment in the following top five areas of nanotechnology product development:

1. Semiconductors, nanowires, lithography and printing products
2. Coatings, paints, thin films and nanoparticles
3. Nanostructures, nanotubes and self-assembly
4. Drug deliver systems, diagnostics and medical implants
5. Nan-biotechnology, nanofluidics and tissue engineering

Other significant products for which organizations are partnering or seeking access to capital equipment include: energy, battery, catalyst, fuel cells and filtration products; environmental sensing and remediation products; and defense, security and protection gear.

On the other hand, survey respondents involved in nanotechnology product categories such as personal care, nanofluidics and colloids; computing, design and imaging tools; and convergence products – were least likely to partner for access to capital equipment.

Respondents who selected this option also indicated the following top five application markets their organizations are pursuing in nanomanufacturing:

- Nanotechnology Equipment, Logistics and Distribution
- Electronics and Semiconductors
- Computing, IT and Telecommunications
- Aerospace
- Automotive

It is noteworthy that respondents from organizations pursuing pharmaceutical, biomedical and biotechnology applications, as well as food and agriculture applications of nanotechnology were the least likely to choose this driver for partnering. This trend is understandable, as the nanotechnology applications targeted for consumption or direct use with humans require highly specialized capital equipment that has stringent monitoring, safety/toxicity and regulatory compliance requirements. Thus, the larger players in these application markets appear to have invested in such equipment for exclusive use within their respective organizations, and are unlikely to access shared facilities at the universities or government labs.

These respondents also ranked the following five top barriers they face in nanomanufacturing commercialization efforts:

1. High cost of processing
2. Lack of investment capital
3. Perception that nanotechnology products take a long time to market
4. Process scalability
5. Shortage of qualified manpower

The detailed list of nanotechnology products being pursued is illustrated in Figure 4-25.

Nearly 40% of the smallest organizations (less than 10 staff) indicated their primary partnering driver was the need to access capital equipment for developing or commercializing nanotechnology products (Figure 4-26). When analyzed further, the trends in this partnering category appeared to be the most interesting and varied, as discussed below.

By Organization Role

A significant proportion (about 26%) consisted of education/academia-based respondents, closely followed by companies identified as manufacturer/integrator of nanotechnology products (25%) (Figure 4-27). This statistic is large as a result of the NNI, and should be regarded as an important outcome of the government investments in programs such as the National Nanotechnology Infrastructure Network (NNIN), and Nanoscale Science and

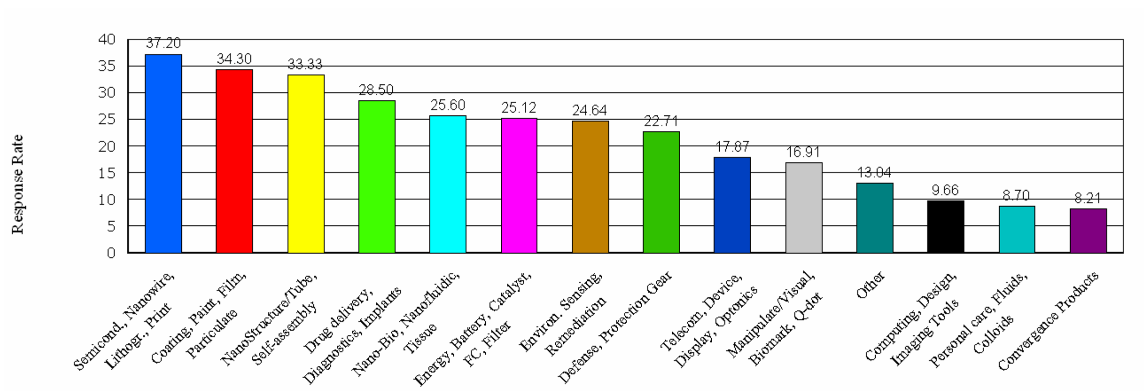


Figure 4-25. Nanoproducts Being Developed by Organizations Who Partner to Access Capital Equipment

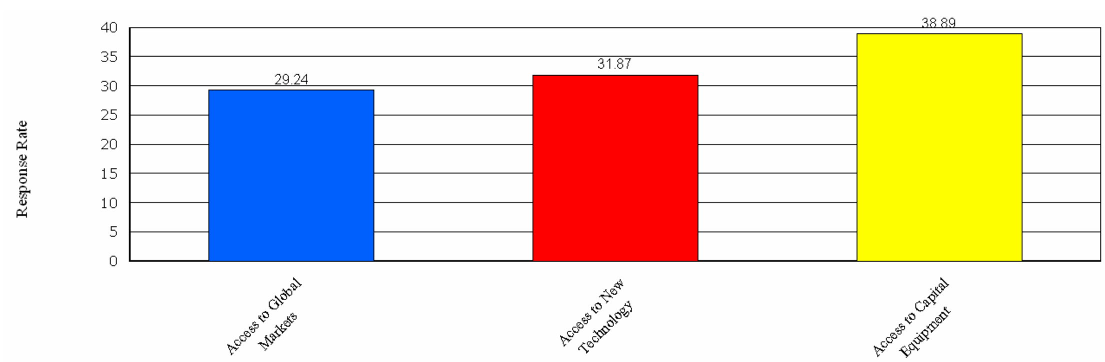


Figure 4-26. Smaller Organizations Partner to Access Capital Equipment for Developing Nanotechnology Products

Engineering Centers (NSEC), which encourage academic partnering with industry.

By Organization Size

Small nanotech businesses and start-ups comprised over three-quarters (80%) of the respondents who stated their organizations partner to access capital equipment for nano-manufacturing, as illustrated in Figure 4-28. These organizations struggle the most with the high costs associated with building and maintaining nanotechnology processing facilities while trying to develop viable nanotechnology products or processes. NCMS believes such organizations typically team with academia and government laboratories for access to specialized equipment and expertise.

About half (51%) of respondents from the smallest commercial organizations (less than 10 staff) who stated they primarily partnered in order to access capital equipment also previously indicated that they lacked internal infrastructure for nanotechnology developments. These were comprised chiefly of the following three significant categories of respondents:

- 50% were small manufacturer/integrator organizations (Figure 4-29) – these small manufacturers of nanotechnology products partner externally in order to access specialty equipment.
- Half are small businesses with roots in education/academia (Figure 4-30) – this trend provides further corroboration that many university faculty and/or researchers (or recent graduates) are opportunistically engaged in start-up businesses to commercialize the advances they developed from sponsored nanotechnology R&D. There is a high probability that the seed funds originated in NSF's grant mechanisms.
- Nearly two-thirds (63%) of respondents from private contract R&D labs (Figure 4-31) – many of whom may be using the Small Business Innovative Research (SBIR) and Small Business Technology Transfer Research (STTR) funding avenues to access specialized nanotechnology equipment either at the National Laboratories or at academic institutions.

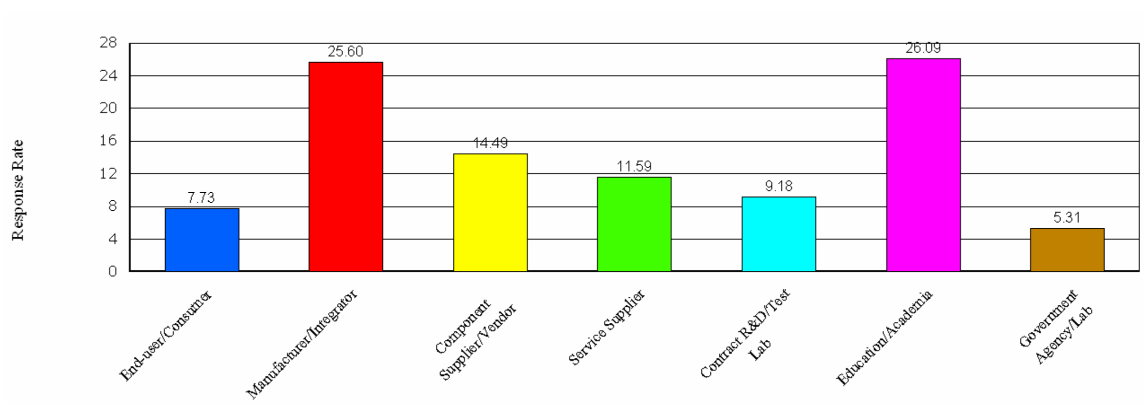


Figure 4-27. Organizations Involved in Partnering to Access Capital Equipment for Nanomanufacturing

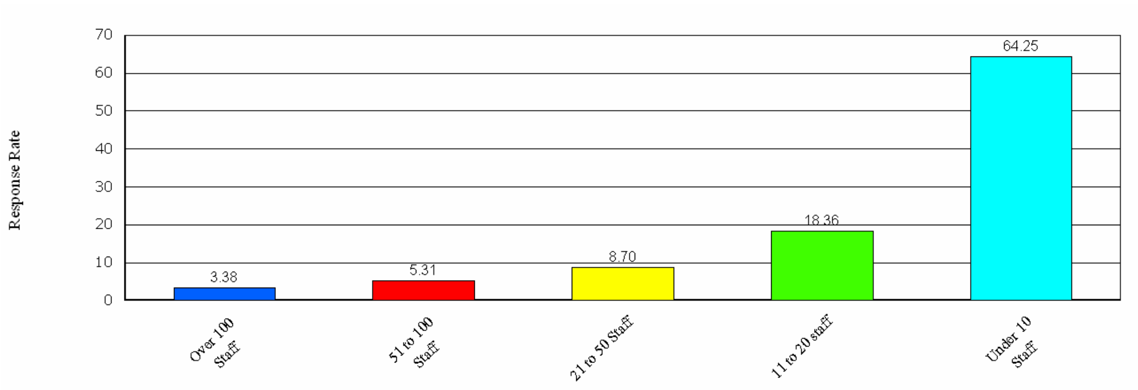


Figure 4-28. Smaller Nanotech Organizations are the Most Likely to Partner for Gaining Access to Capital Equipment

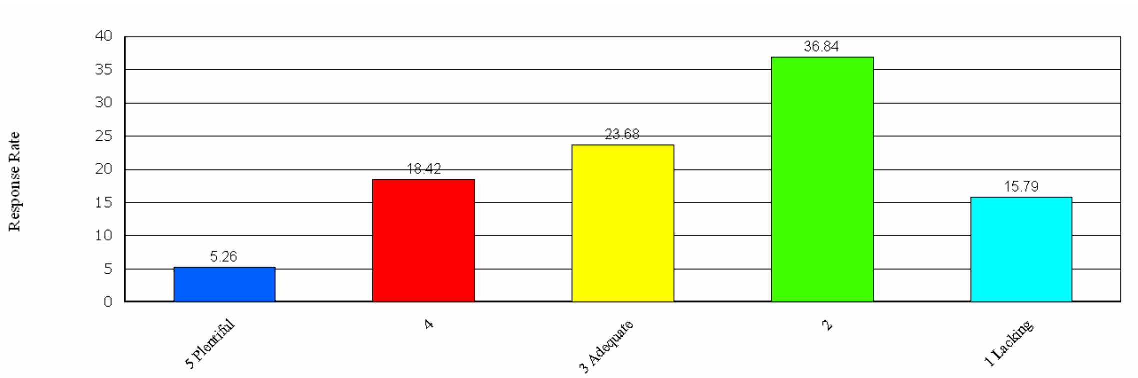


Figure 4-29. Percentages of Small (< 10 staff) Manufacturer/Integrator Organizations that Indicated Inadequate Internal Infrastructure and also Partnered for Capital Equipment Access

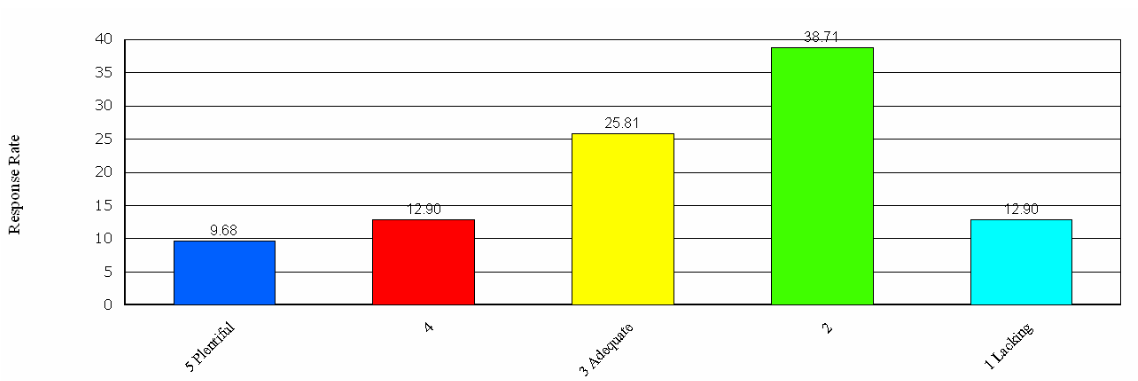


Figure 4-30. Percentages of Small (< 10 staff) Educator/Academia Organizations that Indicated Inadequate Internal Infrastructure and also Partnered for Capital Equipment Access

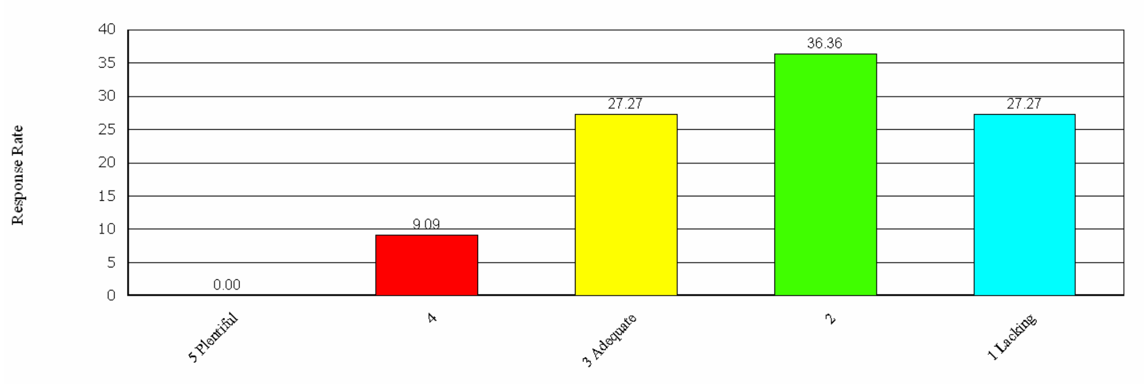


Figure 4-31. Percentages of Small (< 10 staff) Contract R&D Organizations that Indicated Inadequate Internal Infrastructure and also Partnered for Capital Equipment Access

4.2.9 Staffing for Nanomanufacturing

Over 80% of nanotechnology businesses are smaller (< 20 staff), entrepreneurial, technology-heavy entities comprised of start-ups and spin-off organizations; only 5% employ over 100 staff – a rational re-categorization of business entities by size is recommended to better address the unique needs of the nanotechnology industry.

4.2.9.1 Results

The number of employees engaged in commercialization developments amongst the nearly 600 respondents' organizations is listed and illustrated in Figure 4-32:

- 57.5% – Less than 10 staff
- 18.2% –11-20 staff
- 12.3% – 21-50 staff
- 6.7% – 51-100 staff
- 5.2% – Over 100 staff

Staffing patterns in nanotechnology organizations follow similar trends observed early in other fast maturing industries such as biotechnology, with a few key differences. While the electronics and semiconductor manufacturers have indicated larger staffing levels (located in the Pacific, West South

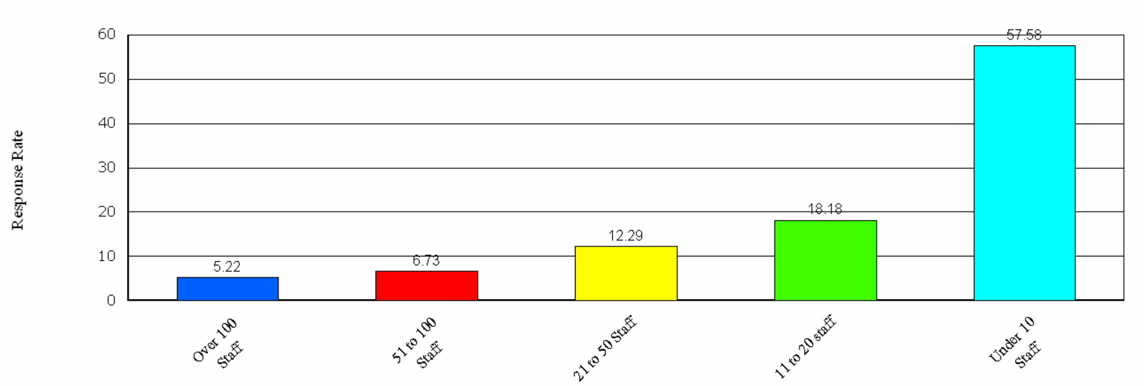


Figure 4-32. Nearly 75% of Nanomanufacturing Organizations Have Less Than 20 Staff

Central and New England regions), the majority of nanotechnology businesses tend to be smaller, entrepreneurial, technology-heavy entities comprised of start-ups and spin-off organizations.

NCMS recommends a re-classification of the conventional definition of "small" business, as many of the largest organizations working with nanotechnologies would be considered small businesses by traditional industry standards. The following three broad re-classifications are suggested in addressing the unique needs of current generation of nanotechnology businesses:

- Small nanotechnology businesses (less than 20 staff)
- Medium nanotechnology businesses (21-100 staff)
- Large nanotechnology businesses (over 100 staff)

These nanotechnology businesses, by themselves, have limited potential for generating the large-scale growth of jobs and commoditization of raw materials that has occurred in traditional (macro-scale) manufacturing sectors. This is because such nanotech businesses require fewer, but highly skilled knowledge workers and technicians who are trained to understand the new multidisciplinary, production methods, handling equipment, analytical and testing techniques. The organizations involved with first generation (passive) nanotechnology have little (if any) resemblance to the large, full-service tier suppliers traditional industry is used to dealing with for new products and components, although no significant nanotechnology product platforms are as yet evident beyond tailored coatings and nanoparticulates.

Industry consolidations will likely occur in the next 3-5 years through growth generated from initial public offerings (IPOs), acquisitions or cross-licensing of nanotechnology advances and patents to larger players and partners, resulting in at least a net preservation of jobs. This is in contrast to the rapid organic job and infrastructural growth which propelled other recent technology waves such as the Internet and biotechnology. Incremental, highly selective, job growth is anticipated in the transition to larger-scale nanomanufacturing with specialized top-down and bottom-up machine-tools, logistics equipment and unique characterization/measurement systems that are required in order to make macro-scale products with nanoscale components or dimensions. The key to this growth lies in the industry's ability to innovate cost-effective, large-scale production methods.

Over the longer term, the potential for achieving significant growth of new, value-adding jobs to the U.S. economy lies in how well nanotechnology products integrate and improve the performance of existing products and impact our quality of life. State and Federal governments can significantly enable growth in staffing by addressing the following key factors directly affecting nanotechnology businesses:

- Production of, or access to specialty raw materials that enable nanomanufacturing
- Adaptation of nanotechnology and its products into existing advanced manufacturing processes
- Access enabled to specialty tools and logistics/handling equipment needed for manipulation, test, assembly and inspection of nanomanufactured products
- Installation of ultra-clean manufacturing facilities
- Provision of adequate training facilities and infrastructure for the development of skilled manpower.

4.2.10 Commercialization Timelines

60% of the respondents expected to market nanotechnology products by 2009. Organizations in the Pacific region appear to have a steady stream of new product introductions across all timeline categories. Medium-sized (21-100 staff) nanotechnology organizations appear best poised for growth, partnering or acquisition.

The current nanotechnology industry is estimated to be worth $40 billion, with established applications in products such as paints, cosmetics, microelectronics, semiconductors and specialty coatings and tooling [5]. These and many emerging nanotechnology markets are expected to grow rapidly in the next decade (given a worldwide nine-fold investment in nanotechnology R&D since 1997) to $1 trillion by 2015, as projected by Roco and Bainbridge [6]. Other estimates of nanotechnology market growth are even higher, including a recent one published by Lux Research [7].

4.2.10.1 Results

By Aggregate

Aggregate cross-industry estimates of commercialization timelines reported by nearly 600 survey respondents are shown Figure 4-33. Organizations in the Pacific region appear to have a steady stream of new product introductions across all timeline categories, which correlate with increased semiconductor and bio-nanotechnology development activity.

Eighteen percent (18%) of the aggregate respondents indicated their nanotechnology products are already commercially available. The proportion of respondents indicated market entry with nanotechnology products was the highest in the Mountain (25%) and the East North Central (17%) regions, corresponding with the strong growth of nanostructured coatings, specialty barriers and thin films, nanocomposites and other particulate applications.

Many nanomanufactured products are expected to enter the market in the near term (2007-2011), with nearly 60% of the aggregate respondents expecting to have marketable nanotechnology products in the next three years (2007-2009). Regions indicating the highest proportions of introductions within three years were West North Central (42%), New England (40%) and Mid-Atlantic (36%) regions.

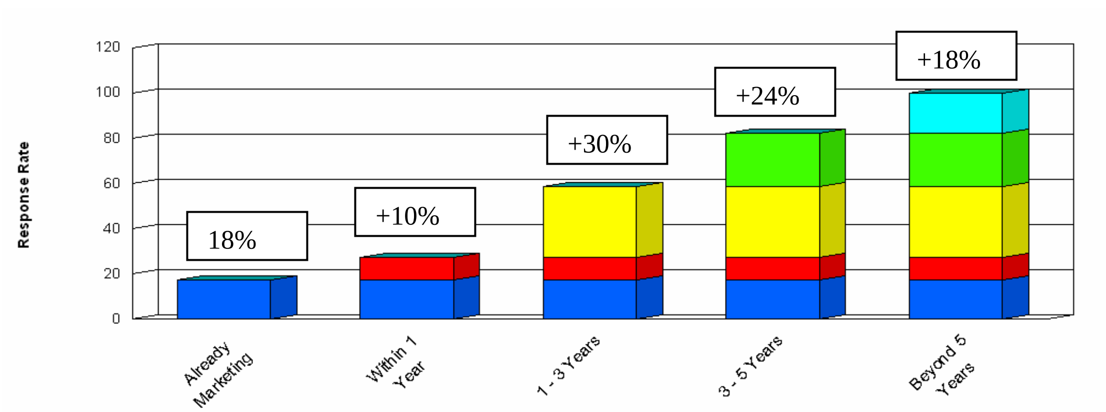


Figure 4-33. Commercialization Timelines Indicate Many New Nanoproduct Introductions in 2007-2011

Twenty-four percent (24%) of aggregate executives indicated their organizations will introduce new nanotechnology products in the 3-5 year time frame (2008-2010). The remaining one-fifth of survey respondents indicated their organizations expect to reach the market well beyond five years – this selection was indicated by organizations in the Pacific (19%), East North Central (19%), South Atlantic (19%), and West South Central (24%) regions.

NCMS believes these advanced products will likely include early applications of revolutionary self-assembly and future convergence products as part of new medical and pharmaceutical drug delivery devices that have long development, testing, and approval cycles.

The top three commercialized products already available on the U.S. market include:

1. Semiconductors, nanowires, lithography and print
2. Nanostructured particulates and nanotubes
3. Coatings, paints, thin films, and nanoparticles.

By Organization Size

Of the larger (>100 staff) organizations, 38% stated they are already marketing nanotechnology products, and are located in the Pacific, East North Central and New England regions; another 30% indicated they will enter the market in the next 3-5 years; and 16% expect to commercialize nanotechnology products well beyond the five-year timeframe (Figure 4-34).

The corresponding timeline chart for small (< 20 staff) organizations is shown in Figure 4-35. For obvious reasons (such as resource constraints, investors being opportunistic for short-term gain and exit or founders driven to be acquired by larger players, etc.) smaller companies tended to be focused on nearer term product commercialization initiatives. About one-third (34%) of these small businesses indicated they planned to commercialize nanotechnology products within 1-3 years; and about one-fifth (20%) will go to market in 3-5 years; nearly a quarter of these organizations (23%) expect to introduce nanotechnology products in the longer timeframe beyond five years. The majority of such small businesses are located in the Pacific, East North Central, Mid-Atlantic and New England regions of the U.S.

Medium-sized (21-100 staff) nanotechnology organizations appear to be the best prepared for commercialization of new nanotechnology products, as shown in Figure 4-36 – over 90% of these respondents expect to have commercial products within less than five years. These “medium-sized” organizations appear to have overcome initial growing pains of “crossing the chasm,” with viable nanoproducts, and have attracted both, investors and professional management, identified significant profitable nanoproduct applications to generate revenues, have access to critical R&D infrastructure, and are thus, the most desirable for merger/acquisition or even IPO status. The majority of these organizations are located in the Pacific, East North Central and Mid-Atlantic regions of the U.S.

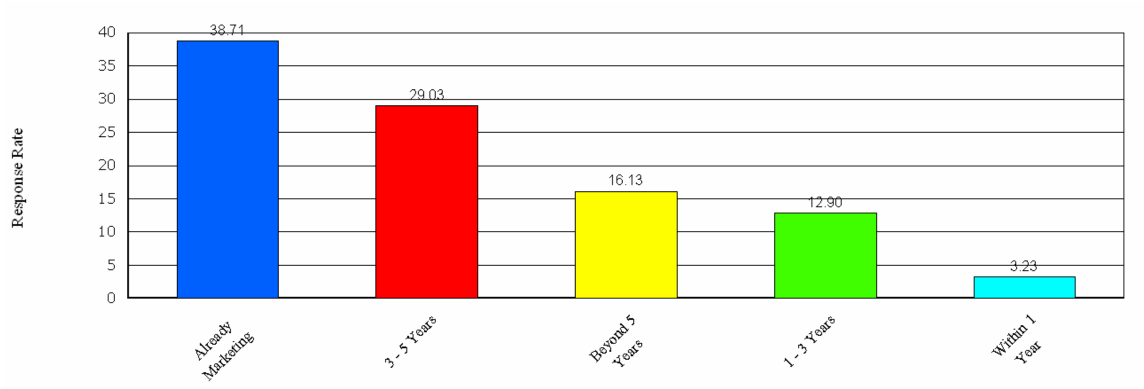


Figure 4-34. Nanotechnology Commercialization Timelines for Large (>100 staff) Organizations

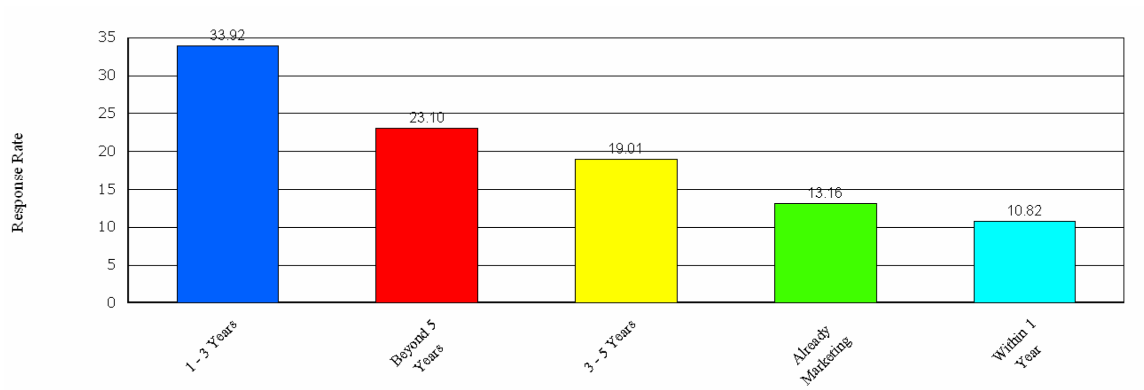


Figure 4-35. Smaller Nanotechnology Companies Have Shorter Product Commercialization Timelines

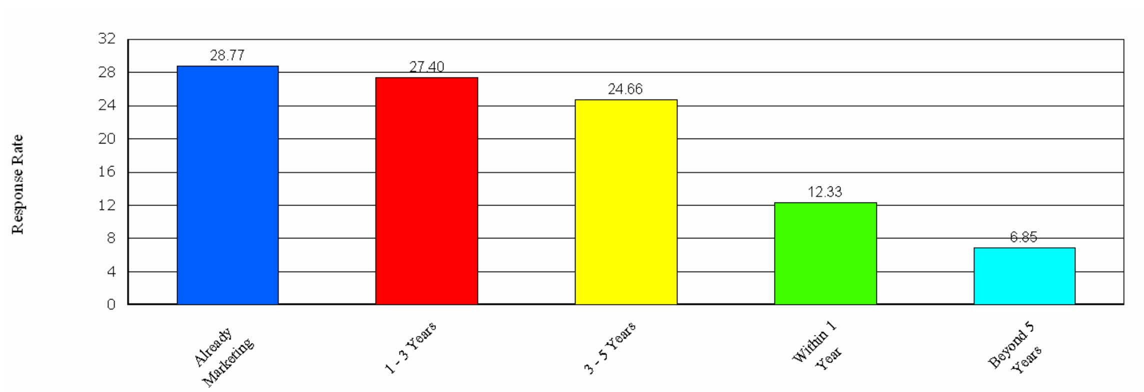
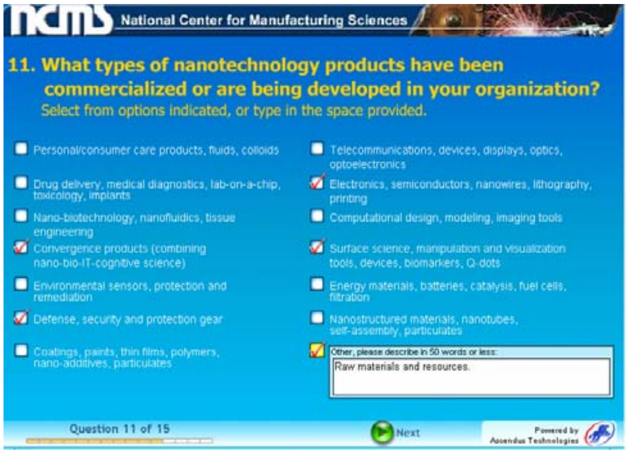


Figure 4-36. Medium-Sized (21 to 50 staff) Nanotechnology Firms are Most Likely to Commercialize Products in the Near-Term

4.2.11 Nanotechnology Products

Diverse products incorporating nanotechnology are in varying stages of development and commercialization.



Respondents were asked to select from a grouped list, and also had the opportunity to enter their own description.

A wide variety of products incorporating nanotechnology are in varying stages of development and commercialization in the U.S. The major categories of nanotechnology products and application markets are summarized in Appendix A. While the semiconductor technology has already commercialized microchips and memory devices with nanoscale features and transistor gates, other commercially available products range from basic nanoproducts and materials (e.g. consumer/personal products), to nanocoatings and thin films that are also on the market. Roco and Bainbridge [6] have predicted these products are likely to increase in complexity, and will serve as building blocks for other active nanostructures, eventually expanding to molecular engineered systems with self-replicating capabilities, and convergence systems. The survey findings corroborate these predictions. These latter two categories of molecular nanotechnology products are regarded as amongst the most complex manifestations of nanotechnology, and would need to overcome many regulatory, integration, legal and societal hurdles prior to commercialization [8].

Note that nearly one-fifth (19%) industry executives did not provide specific nanoproduct information in the 2003 NCMS survey, which was attributed to high levels of secrecy and confidentiality in the industry. This time, NCMS observed a greater level of openness amongst industry executives to share information, which may be attributed to:

- Increased corporate, shareholder and public awareness of both nanotechnology risks and its potential to deliver superior returns
- Availability of higher government funding levels in the U.S.
- Growing numbers of industry studies and benchmarking worldwide
- Growing government interest and media calls for industry regulation
- Marketing/branding of new, extreme-performance consumer products as "nano-" (most such products are not really "nano"!)
- Media "hype," and new science fiction novels.

An attempt was also made to correlate the types of nanotechnology products to the commercialization timeline options selected by respondents in Question 10, in order to develop a general idea of what future trends may become apparent. These are discussed below.

4.2.11.1 Results

By Aggregate

A greater diversity of nanotechnology products are in development in organizations located in the Pacific, New England, Mid-Atlantic and South Atlantic regions of the U.S.

The top passive nanotechnology products already commercialized or soon to be commercialized in the foreseeable future (up to three years out), comprise higher precision materials, manipulation tools and devices for enhanced manufactured goods, equipment and sub-components such as:

1. Semiconductors, nanowires, lithography and print products
2. Nanostructured particulates and nanotubes
3. Coatings, paints, thin films, and nanoparticles
4. Defense, security and protection gear
5. Telecommunications, displays and optoelectronics products

In the 3-5 year timeframe, nanotechnology products entering the market with the highest growth rates include a larger proportion of biomedical and nano-biotechnology:

1. Environmental, sensing and remediation products
2. Drug delivery, medical diagnostics and implant systems
3. Nano-biotechnology, nanofluidics and tissue engineering products
4. Computation, design, visualization, Q-dots, biomarkers and imaging tools
5. Energy-related battery materials, catalysts, fuel cell components and filtration products

Examples of new coating, packaging, sensing, energetic and protection products that are fast reaching commercialization for early adopter markets[1] include:

- Nanoparticulates and additives for improved functionality (strength, water resistance, absorbance, gloss, barrier properties, conductivity)
- Nanotechnology-enabled photovoltaics printed directly onto building materials – an approach that simply is not possible with conventional crystalline silicon solar materials
- Nanocomposite magnetic materials for tag sensors
- Polymer/clay nanocomposites for improved barrier properties
- Nanoparticle filled polymers for structural, security and protection applications
- Plastics for bottle applications with gas and UV barrier properties
- Miniature nano radio frequency identification (RFID) tags
- Nanoscale barcodes and taggants to track, trace and provide brand protection (e.g. in pharmaceutical and currency applications)
- Reinforcement coatings for polymer nanocomposites
- Inks, paper and plastics with tailored sensing ability
- Nanocoded plastics and paper materials for authentication and identification applications
- Intelligent packaging systems

These product introduction trends will continue beyond the three to five year timeline (2009-2011), with even greater growth, complexity, and diversification of products and application markets. The survey information corroborates the forecast by Rittner, predicting significant growth of commercial nanostructured nanoparticles such as dry powders and liquid dispersions [9]. It is also anticipated that new fuel cell catalyst coated membranes and other components made with bottom-up processes will be commercially viable in that timeframe.

New environmental sensing and remediation, as well as drug delivery, diagnostics and implant systems are likely to enter the market in larger quantities as the industry's capability evolves to

[1] Personal communications in December 2005 with T.S. Sudarshan, Vice-President of Material Modification Inc., Fairfax, VA and member of National Materials Advisory Board.

engineer, design and replicate precise materials, measurements and processes. Significant contributions are expected from concurrent developments in computational, design, manipulation, imaging and visualization tools, Quantum dots and other bio-markers.

The survey results also indicate that self-assembly and convergence nanotechnology products will be commercialized well beyond five years.

4.2.12 Government's Role in Nanomanufacturing

Nearly 95% respondents favored government involvement in the commercialization of nanomanufacturing, most preferring strong and meaningful incentives for industrial adopters of nanotechnology.

Public policies and long-term National strategies have a crucial role in accelerating the commercialization of nanotechnology, as well as may act as hindrances if the industry is over-regulated, resulting in the erosion of the Nation's technological lead in this area [10]. In the post-World War II era, the primary purpose of Federally-funded research policy has been to ensure the country's dominance in areas such as the military (e.g. nuclear, electronics, avionics, and advanced materials), energy, health, education, basic sciences, etc. Military R&D has always taken precedence in order for the U.S. to expand its reach and global superiority, while being prepared to handle any natural or manmade crisis. Nanotechnology is widely thought to have the answers to many of the current problems human society faces, and regarded as the enabler for several future waves of enormous economic opportunity that range from bacterial factories to silicon photonics to quantum wires. It is imperative that the U.S. government continue to fund cutting edge R&D, as well as implement policies that help keep the Nation unsurpassed in nanotechnology.

Survey respondents were presented five different perspectives on the role of the government as an investor, and were asked to select one that was best suited to their organizational goals.

4.2.12.1 Results

By Aggregate

The responses for this question were strikingly similar to the 2003 NCMS survey – nearly 95% respondents wanted a degree of government involvement in the commercialization of nanomanufacturing. NCMS believes this trend is partly due to the aggregate respondents' fear that the U.S. could lose its competitive advantage in future nanotechnology innovations due to the rapid growth of offshoring of traditional manufacturing and research operations. Other concerns driving such a high response preference could be the executives' belief that the industry needs continued government funding and new policies addressing nanotoxicity and environmental impact. These unprecedented issues merit the government's proactive leadership in conducting unbiased,"good science" investigations – publication by trusted organizations would help provide the public a high level of confidence that this important industry is conducting R&D in a responsible and safe manner. Another critical area for government leadership lies in expedited approval of new nanotechnology-based drug biologics, devices and "nanoceuticals" (i.e. combination diagnostic, delivery and therapeutic systems) by the Food and Drug Administration (FDA). It is widely held that this can be accomplished by improved early communication and collaboration with developers to identify and address product risks.

The respondents' aggregate selections are illustrated in Figure 4-37.

Over 45% of the respondents felt that nanotechnology commercialization in the U.S. can be significantly accelerated by providing strong and meaningful incentives for industrial adopters. Geographically, the preferences of respondents for this option ranged from 30% (East South Central region) to 47% for Pacific region organizations. The need for effective incentives becomes even more critical as nanotechnology products mature and increase in complexity, functionality and societal impact. The near-term steps the government (State and Federal) can take include:

- Funding programs for greater public education and dissemination about nanotechnology
- Formulating incentive-driven economic and investment policies aimed at changing the behavior of consumers, businesses and investors and thereby facilitating "market pull" forces
- Accelerating "technology push" activities by providing widespread dedicated resources, and issuing "grand challenges" with the redirection of public investments in new nanotechnology research to drive innovation.

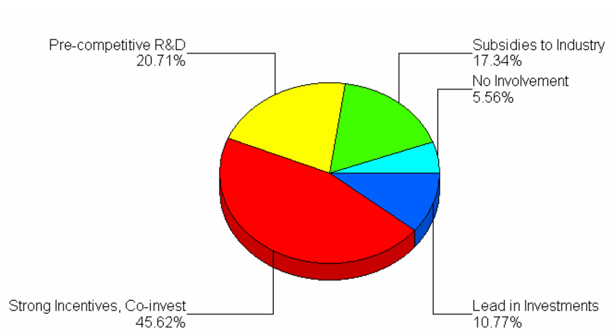


Figure 4-37. Majority of the Nanomanufacturers Prefer a Strong Government Role

4.2.13 Nanomanufacturing Industry Challenges

The aggregate respondents indicated overwhelming consensus around the key barriers affecting the commercialization of nanotechnology. Industry perceives similar challenges and threats at three distinct levels.

The successful commercialization of nanotechnology involves overcoming or addressing many challenges that are similar to any other new technological developments – yet, several barriers faced by the nanomanufacturing industry are unique. Section 5 discusses these barriers in greater detail.

The NCMS survey questionnaire listed eighteen different challenges (most were retained from the 2003 survey), and asked respondents to select the top five challenges. The aggregate selections are illustrated below in descending order.

The majority of nearly 600 respondents indicated overwhelming consensus around the key barriers impeding the commercialization of nanotechnology. The nanomanufacturing industry perceives similar challenges and threats at three distinct levels (Figure 4-38).

At the first level, the critical top five aggregate (common) industry barriers are:

1. High cost of processing
2. Perception of lengthy times to market for nanotechnology products

3. Insufficient investment capital
4. Process scalability
5. IP issues

The second tier challenges include:

1. Shortage of qualified labor
2. Regulatory and safety concerns
3. Perception of unclear societal benefits
4. Environmental and toxicity concerns
5. Multidisciplinary aspects and complexity

The third tier challenges are:

1. Manufacturing resource impediments (i.e. supply-chain issues)
2. Foreign competition
3. Lack of development tools

The top half dozen barriers indicated in 2005 are generally similar to the top industry concerns identified by 81 respondents in our 2003 survey which were:

- 15% nanotechnology products are perceived to be a long way from commercialization
- 14% insufficient investment capital
- 12% IP issues impede commercialization progress
- 11% process scalability
- 11% high cost of processing
- 9% societal benefits of nanotechnology not yet recognized.

In this latest 2005 NCMS survey, environmental, regulatory and safety concerns were elevated as important second-tier barriers to the industry, and ranked higher in aggregate than foreign competition, which is not considered an important enough (or urgent) barrier for U.S. manufacturers. However, foreign competition became a significant higher ranked barrier when the data were analyzed within selected industry sectors. The top-ranked industry barriers are discussed in greater detail in Section 5.

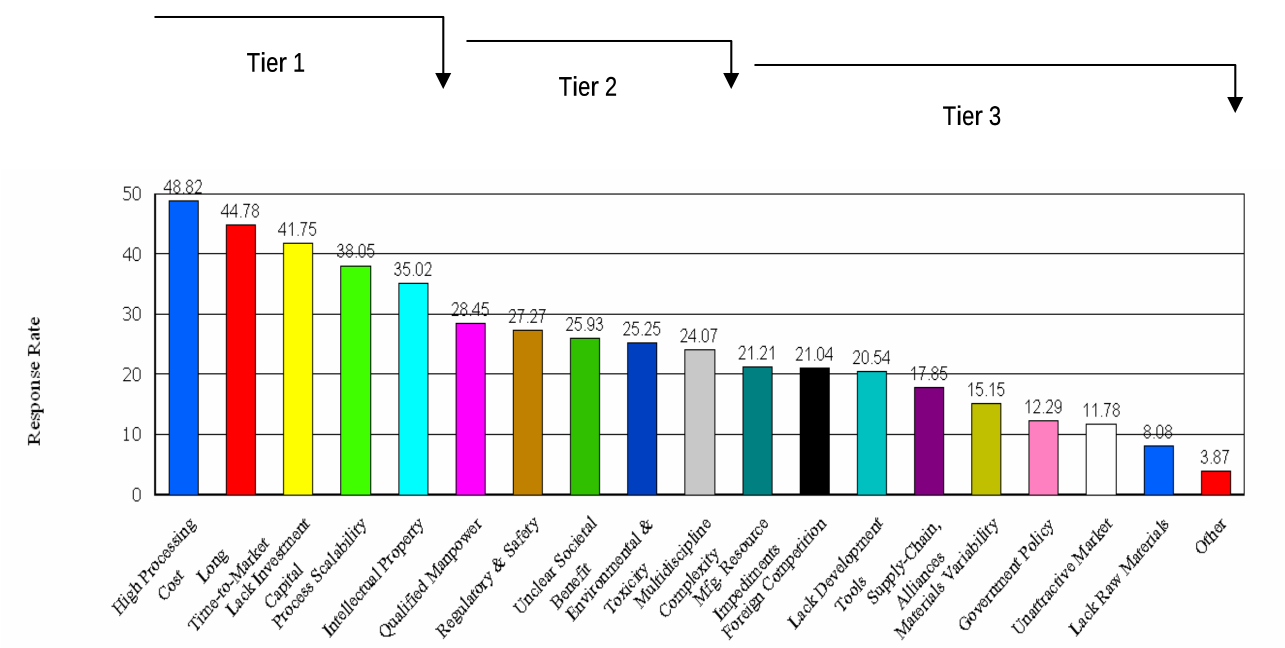
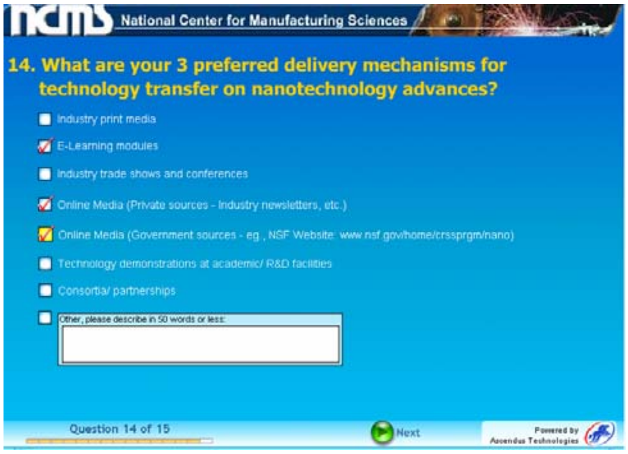


Figure 4-38. The Aggregate U.S. Nanomanufacturing Industry Faces Three Distinct Tiers of Barriers

4.2.14 Technology Transfer Preferences

Respondents expressed differing preferences for accelerating "nanoknowledge" transfer mechanisms across the manufacturing value-chain.



This question, with seven response options was included in this survey at the request of the NSF sponsors. NSF has developed a rich website on nanotechnology, http://www.nsf.gov/nano, and the sponsors wanted feedback on how it compares with other options (see option labeled Government Online Media). Respondents also had the opportunity to recommend new mechanisms for technology transfer.

As a diverse manufacturing R&D consortium, NCMS wanted to assess what media sources and "nanoknowledge" transfer mechanisms the industry relies on for both, scouting (technology pull) and dissemination (technology push) activities, and to identify the most effective ways to accelerate technology transfer for nanomanufacturing.

Figure 4-39 illustrates the top three picks of aggregate survey respondents:

1. Industry trade shows and conferences
2. Technology demonstrations
3. Industry online media.

4.2.14.1 Results

By Organization Role

End-users of nanotechnology products ranked government online media, technology demonstrations and industry print media as their highest choices. Respondents from larger (over 100 staff) also selected these same preferences.

Manufacturers/integrators, however, expressed higher preference for knowledge transfer by trade shows/conferences, consortia/partnerships and industry online media.

Suppliers/vendors of nanotechnology products ranked trade shows/conferences highest, but showed equal preferences for industry online media, consortia/partnerships and technology demonstrations.

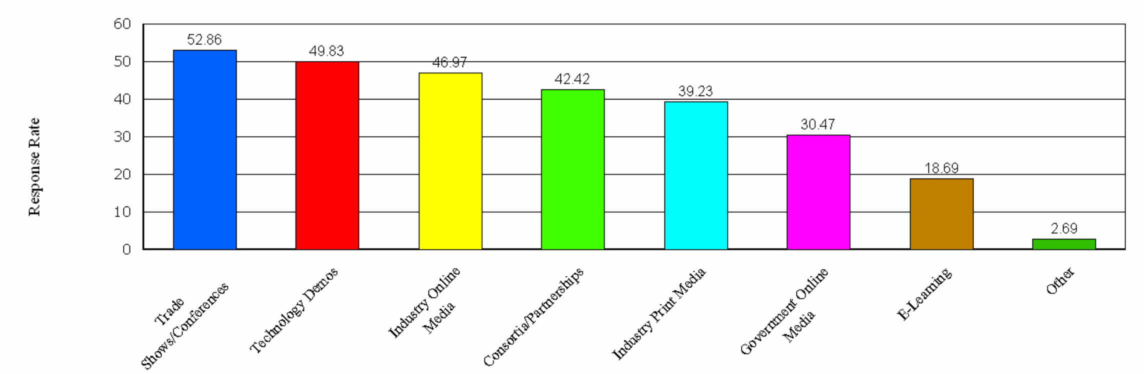


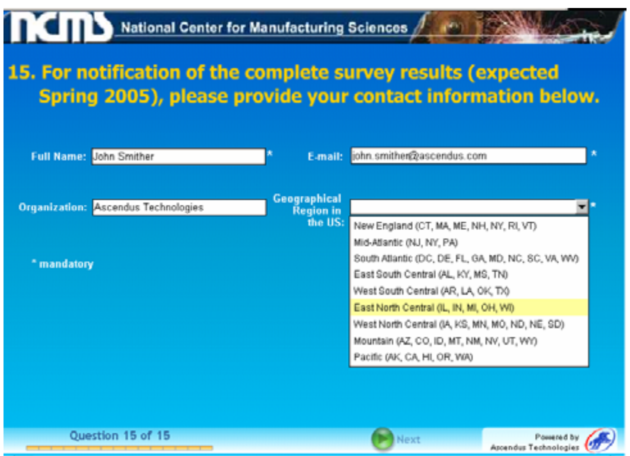
Figure 4-39. Preferences of Survey Respondents for Effective Nanoknowledge Transfer

Service suppliers selected industry print media, trade shows/conferences and technology demonstrations as their preferred modes of technology transfer.

Government R&D labs developing nanotechnology indicated technology demonstrations, industry online media and trade shows/conferences as their top knowledge transfer mechanisms.

Education/academia-based respondents overwhelmingly ranked technology demonstrations, followed by trade shows/conference and consortia/partnerships as their top choices, and were also more likely to select e-Learning.

4.2.15 Survey Demographics



In exchange for providing their contact information and affiliation (primarily intended for random authentication of responses), survey respondents were assured of confidentiality of individual responses. A final screen thanked individual respondents for sharing information, invited them to nominate colleagues to take the survey, as well as provide comments or feedback to NCMS.

5. Top-Ranked Industry Barriers

5.1 High Processing Costs for Nanoproducts

The fact that a very high percentage of cross-industry respondents selected the high processing cost of nanoproducts as a major barrier indicates that the evolving nanomanufacturing industry is largely in its infancy, characterized by few early adopter applications, and fragmented nanoproduct markets. Besides the mass application of nanoscale engineering in semiconductor and photovoltaic manufacturing, most other nanoproduct manufacturing involves the development of infrastructure equipment and manufacturing methods for "prototype" quantities of trial products that are largely aimed at facilitating evaluations by stakeholders. Like other early technology waves, these methods are presently very expensive, involving significant human skill and labor content for performing rigorous analyses and verification steps necessary for confidence-building.

Early adopter end-users and consumers would (obviously) prefer customized products at competitive prices; these early adopters cannot easily afford to replace conventional materials with high-cost nanoproducts for achieving only incremental enhancements – the benefits of nanotechnology products have to be unambiguous and compelling. Thus, nanotechnology organizations need to aggressively research and continuously improve ways to deliver exact products at prices competitive with those of mass production. Like the semiconductor and traditional industries, nanomanufacturers face similar high fixed costs due to involved processing, testing and characterization steps. However, by rapidly achieving standardization of macro- and nano- scale parts, equipment/tooling and product offerings, they can begin lowering their marginal costs, as well as reduce their average production costs by manufacturing larger quantities of (identical) platform nanoproducts, thereby spreading the large fixed costs over increasing product quantities. This level of maturity is fast being achieved in the manufacturing of nanoparticulates, and other nanostructured raw materials such as carbon nanotubes. The technical and processing challenges remain significant in case of active, 3D nanostructured components and their integration into macro-scale devices and systems.

Manufacturers that are capable of developing and implementing techniques to change nanoproduct platform designs quickly and inexpensively, are more likely to win new customers by targeting individual preferences and requirements. By adopting other modern manufacturing technologies with trained staff, an organization's average processing costs for nanoproducts can be driven down without long production runs. This mass customization could become optimal when both fixed and marginal costs are low.

5.2 Lack of Investment Capital

The lack of investment capital was consistently listed high by nearly all surveyed organizations and particularly by the small business respondents – it is a complex issue due to several interacting factors. The reasons are numerous, inter-dependent and even application sector-specific. What is common to nanotechnology is that most organizations struggle with the high costs of building and maintaining nanotechnology processing facilities while trying to develop viable nanotechnology products or processes. The Small Business Association (SBA) reports that the regulatory compliance costs per employee are at least double the compliance cost for medium-sized and large firms. The National Coalition for Manufacturing (NACFAM) reports that small businesses (fewer than 20 employees) annually spend $7,647 per employee to comply with Federal regulations in manufacturing than the $5,282 spent by firms with over 500 employees [11]. In many small technology-focused nanotechnology businesses, the cost of patents and fees are a major cost center, often ranking next to payroll [12].

Established manufacturers of conventional products also reported some difficulty with obtaining funding utilizing nanotechnology – it is possible these respondents were alluding to the lack of understanding of nanotechnology at senior management levels where R&D budgets are developed and priorities defined often on the basis of set returns-on-investment or within specific timelines.

One reason often cited in meetings with VCs and institutional investors was the inability of many scientists and entrepreneurs to explain the value proposition of their selected nanotechnology products, and therefore, make a stronger case for external investment.

Another key factor contributing to this lack of investment capital is the market's perception that significant (i.e. disruptive) nanotechnology products have a long time to reach commercialization and many different risk-laden hurdles to overcome that range from complex intellectual issues (discussed asunder). This makes it hard to attract investors (angels, VCs or institutional) to many industry start-ups pursuing longer time-to-market nanotechnology products. When compared to potential returns investors stand to gain from other less risky and shorter-term investments (e.g. in electronics, IT, healthcare), these nanotechnology organizations lose out. This issue makes a strong case for sustained government funding for long-term R&D in nanotechnology.

Organizations seeking investments for the nanotechnology industry need to better exploit the market's short-term mentality by aggressively pursuing the major enabling applications and high-profile product enhancements in order to demonstrate early successes and potential for significant future shareholder returns. The industry's capacity to attract large amounts of private capital and new partners depends on the ability of nanotechnology entrepreneurs to address critical and pervasive National concerns (energy, cost, productivity and healthcare) with viable solutions and improvements to existing manufacturing processes, equipment and products that would make them cheaper and more profitably. This may be a more practical strategy for attracting opportunistic investors while applying new concepts from nanotechnology or bioengineering.

The financial markets, especially large VCs, are increasingly funding technologies in renewable energy applications that have the potential for making existing energy plants and infrastructure cleaner and more efficient, investing an estimated $4.4 billion in 2004 in the energy-technology sector. VC investments directed at power plant improvements alone grew from a scant $3.0 million in 1995 to $180 million in 2005, according to the National Venture Capital Association. The healthcare VC market grew to over $7.0 billion in 2005, within which biopharmaceuticals attracted nearly $2.1 billion, followed by medical devices and pharmaceuticals [13]. Some of these investments involve nanotechnology applications, but the vast majority do not involve nanotechnology solutions. With the gradual maturing of the biotechnology industry, the overall trend is that investor interest is shifting away from the development of biotechnology itself, toward what can be developed using biotechnology – i.e. biopharmaceuticals, which may involve use of new nano-bio technology-based products and compounds.

Recent consolidations and mergers in the financial markets and the resulting creation of mega-VC organizations may also potentially improve investment access opportunities for nanotechnology companies.

5.3 Perception of Long Lead Time for Nanotechnology Products

Key challenges have to do with the perception that nanotechnology is a long way away from reaching the marketplace, and thus, far from making the pervasive quality of life impacts that are projected by forecasters – i.e. the nano-component or nano-enhancement to existing products is often invisible to the consumer. This issue points to the need for making continued large investments in high-profile nanotechnology projects, accompanied by cross-industry and public-private efforts for spreading greater public awareness on nanotechnology, its human, environmental and societal implications (especially, the benefits "dummied" down), as well as its direct relationship to the Nation's economic and competitive posture. In spite of the U.S. having the world's most widespread nanotechnology facilities and nano-enhanced product diversity already in the marketplace, as well as the availability of multiple outreach options, it is the industry's opinion that the Nation is falling behind in preparing society and the common man for the nanofuture. Federal and State governments, trade and professional groups, and other non-profit organizations and Centers of Excellence have a major role in addressing this barrier through cooperation that can be leveraged on a global scale. Innovative dissemination projects are already underway in many European and several Asian nations that have been proactive in reaching out to the public. Addressing this barrier would not only improve awareness in mainstream industries but also help accelerate novel nanoproduct developments, while attracting larger numbers of future scientifically-oriented workers.

5.4 Lack of Process Scalability

The upgrading of nanotechnological processes and the integration of nanoparticles into other dissimilar materials with reproducible performance and properties, remain important technically challenging issues to the industry – they are far more significant for industry sectors dealing with human applications than other more passive uses. While tighter size control and uniformity of distributions have been achieved in several nanoproduct applications (notably in nanotech applications to personal care products, digital storage, microelectronics, semiconductor, photovoltaic deposition and nanostructured coatings and thin films), the nano-bio and bio-medical materials areas remain the most challenging areas where technological breakthroughs are needed in transitioning from lab-scale to pilot-scale prototype production and to provide evaluation quantities for end-users. One key consideration that makes product design at the micro- and nanoscales especially challenging relates to chemical and biological induced loads to machine structures. These loads are not clearly understood, nor are they formulated in a way that allows reliable engineering design predictions to be made. While many stand-alone devices and structures are in development, the integration of these structures across 3D macro-scales into operational products is still in its infancy. Photolithography and nano-printing processes integrated into high-value plastics have the potential to form the basis of novel 3D nanoproducts for volume-scaleable catalysis, chemical separation and semiconductor manufacturing, but these techniques are still largely 2D processes with limited repeatability, resulting in unacceptable material composition and performance fluctuations reported by many survey respondents.

This high degree of variability of nanomaterials and associated unscaleable nanomanufacturing processes points to the need for increased research, resources and investment in infrastructure for characterizing and quantifying the properties of these structurally complex materials. It is a key impediment to development of second generation bio-nanotechnology products. This implies the need for investigating technologies and equipment for achieving the predictable, precise control and manipulation of material interactions at the atomic and molecular scales. Cost-efficient nanofabrication and self-assembly techniques that reproducibly link engineered properties and performance across multiple lengths-of-scale to the macro-world are critical for the transition to volume nanomanufacturing. New nanoscale understanding of these materials will further enable improved manufacturing and performance efficiencies, allowing fundamentally new ways for nanotechnology products to appear in our everyday lives.

5.5 Intellectual Property Issues

Nearly 52% of survey respondents who were manufacturers/integrators or suppliers of nanotechnology products regarded these unresolved IP issues as a top-five barrier to commercialization. Analysis revealed these respondents are pursuing product applications for the equipment, tooling and logistics, electronics/semiconductors, computing, IT/telecommunications markets. For many small nanotechnology companies, patent fees are already a major cost center and the fear of litigation on conflicting legal claims by multiple researchers patenting nanotechnology, could significantly delay product introductions, affect revenue streams, as well as increase consumer costs, thereby raising the “activation energy” for market acceptance of new nanotechnology products.

Triolo [14] has raised two critical issues with nanotechnology patents that need to “play” out and be resolved in the courts through trial cases and court verdicts: (1) the assertion that smaller is not different; and (2) for infringement issues, the tendency of litigants to expand the scope of their traditional patent claims. Miller [15] and Voigt and Mickelson [16] have also identified other unique challenges with high-knowledge barrier, nanotechnology-related inventions within the context of an infringement suit, which include: difficulty for judges and juries to understand nanotechnology; the lack of prior art in nanotechnology compared to other mature technologies; and the difficulty for attorneys in trying nanotechnology cases, due to the lack of familiarity with nanotechnology.

Thus, IP issues are a key factor inhibiting private investments and the more rapid commercialization of nanotechnology products, since the path to revenue is not apparent to investors and VCs. The recent proliferation of patents on nanotechnology innovations, many of which are regarded as broadly defined and interpreted by the patent awardees, is both, a source of economic opportunity and an impediment.

Aggressive technology transfer practices can be pursued through innovative relationships between academia and industry in nanotechnology developments. For example, NNI programs funded to university-based researchers could be made streamlined with greater transparency to attract and permit industrial partners to pursue their economic goals, while ensuring steady revenue streams for the institutions. This can take the form of granting companies non-exclusive or royalty-free, fully paid up, irrevocable, perpetual licenses to make, use or sell nanotechnology products under university-held patents. Universities could also contribute no-cost assistance to corporations implementing inventions in their facilities, thereby training new workers.

5.6 Regulatory, Health and Safety Concerns

Regulatory concerns with nanotechnology have been raised as a second-tier barrier to nanomanufacturing. These span several key areas that need to be carefully addressed by a combination of government policy and voluntary compliance by industry developing nanotechnology products, since over-regulation will result in detrimental effects such as offshoring, and curtail the U.S. Industry’s competitiveness and leadership.

For nanostructured products such as nanoparticles, coatings, nanoadditives and nanotubes, health and safety are areas of immediate concern that need regulatory approaches developed. Due to many similarities that nanoparticles are thought to have with the ongoing asbestos inhalation hazards, the guidance from regulatory and environmental agencies is that “until more information is available about the health risks nanoparticles pose, work sites should be very careful about protecting their workers” [17]. The industry and policymakers need to take steps to avert the controversies and scare-mongering that have severely curtailed the biotechnology and genetically modified food industry innovations – the lack of timely and balanced regulatory approvals and industry compliance practices continue to be major impediments to public acceptance.

Nanotechnology applied to anticipated next generation active devices offers the possibility of a device and a drug in one, with novel capabilities for achieving diagnostic, imaging and therapeutic goals – this implies the creation of a whole new class of medical systems and devices. The key challenges that lie ahead include development and demonstration of targeted applications for societal benefit, while addressing the safety and regulatory issues associated with such products. Although regulatory compliance might seem daunting for such innovations, strategic planning that incorporates compliance into the product development and manufacturing platform and integrates with the business structure can help commercializing organizations mitigate regulatory risk exposure, while meeting nanodevice performance and business goals.

Registering a medical device firm with the FDA and establishing a medical device listing are two crucial steps to commercialization of novel medical devices in the U.S. With the increased bio-electronic and cognitive (software) content in future nanotechnology-based biomedical devices that could originate from multiple technology and software providers, the already complex challenges of supply-chain security, traceability, regulation, IP content and assigning liability become even more daunting. These issues will impact all players in the value chain – from OEMs to contract manufacturers or firms that provide services or parts to an OEM, as well as firms that provide spare parts or replacements for nanodevices; to even third-party equipment manufacturers, aftermarket repair, refurbishing or reprocessing firms. The industry and policymakers need to anticipate and address these types of regulatory challenges in implementing nanotechnology for drug delivery systems and imaging agents by proactively promoting dialogue. Nanomanufacturers that seek out innovative technological solutions and strong value-chain/commercialization partners to meeting regulatory compliance challenges will step ahead of the pack.

6. Survey Findings and Recommendations

6.1 The Profile and State of U.S. Nanomanufacturing

The state of the U.S. Nanomanufacturing Industry is generally vital, innovative and competitive for established passive nanotechnology products with 2D applications which are rapidly growing via a proliferation of start-ups for many end-uses across manufacturing industries and geographical sectors. The U.S. has the best-developed and mature research facilities, entrepreneurial culture and governance infrastructure for promoting new nanotechnology-driven economic development. However, organizations are proceeding cautiously in the commercialization of innovations such as active 3D nanotechnology products that involve more direct human, societal and environmental impact. The nanomanufacturing industry for such second generation (potentially disruptive) nanotechnology products is still in its infancy – there are as of yet no commercial devices based on true nanotechnology. The challenges facing nanotechnology aren't limited to the technology itself – rather, factors such as funding, commercialization strategies, regulation and a variety of socio-business issues will affect the long-term success of organizations entering this space.

Due to the cross-disciplinary nature and implications of nanotechnology, few organizations possess the vertical integration and networks needed to rapidly commercialize the envisioned products from conception to consumption. While there is much exploratory partnering and co-development within the industry, it will accelerate when the early nanotechnology applications are able to demonstrate incontrovertibly superior performance of existing macro-scale products and systems at affordable cost, improved margins and higher reliability.

Besides the rapidly evolving U.S. nanomanufacturing base for generating nanoscale materials, manipulation tools and measurement innovations in progress to benefit the consumer products, digital storage and semiconductor manufacturing industries, a plethora of new applications of advanced nanocoatings, nanofilms and nanoparticles are being developed for implementation in the near-term (3-5 years) on a broader range of durable goods, consumer electronics and medical products. New nanoproduct applications are being developed for the semiconductor, energy, chemical catalysis and biomedical fields that would eventually mature with higher sensory complexity and autonomous functionality, with ever greater potential for achieving the visionary large-scale economic and societal impact.

The large-scale, market-driven investments have been largely inhibited due to the associated uncertainty of regulation and societal acceptance. Therefore, the near-term impact of nanotechnology is likely to be fragmented, product-specific and incremental rather than revolutionary. The distillation of survey trends and executive attitudes indicates that while these applications will grow in the near-term largely by entrepreneurial means (e.g. technology push to find "killer" applications), the longer-term growth and sustenance of a nanotechnology organization would depend on the organization's core competency to vertically integrate and partner with end-users on the basis of platform nanotechnologies to meet defined performance objectives (i.e. market pull).

These promising trends are attributed to the substantial seed investments, leadership and outreach efforts made by the NNI through R&D undertaken across academia, small and large businesses and the National Laboratory infrastructure. The increased branding of consumer products and coining of science fiction terms (such as IPod-Nano, Nanites, etc.) has also raised societal awareness, albeit with mixed results [18]. Survey respondents unanimously indicated that government sponsorship is essential in order to attract the attention of senior manufacturing industry executives, investors, media and the public. It will also expedite improved fundamental understanding of nanotechnology and its potential, while nurturing both, early markets and entrepreneurship towards the more advanced product applications.

Besides the numerous entrepreneurial start-ups and small businesses (many led by researchers with academic or government laboratory backgrounds), many larger and manufacturers of conventional industrial materials and products as well as OEMs and end-users, have begun to invest in research, actively seek new technologies, and partner in order to evaluate the potential for nanotechnology products in differentiating their current product lines. Many of the world's largest manufacturing organizations are developing their own pipelines and strategies for future products, and view the specialized techniques and focused markets of nanotechnology as a solution. Corporate partnering is critical for embryonic nanotechnology businesses in the face of risk and uncertainty, and to attain growth and viability; it begins anywhere from peer relationships to technology co-development and co-marketing, to culmination in merger and acquisition [19].

6.2 National Priorities for the Near Term

The U.S. nanomanufacturing industry faces many technical and business challenges as described in Section 5, but similarities exist with other recent technology waves such as the Internet and biotechnology, offering many lessons learned for formulation of sound anticipatory approaches. The answers to the top-ranked identified nanomanufacturing challenges lie in pursuing aggressive R&D policies in fundamental nanoscale science, engineering and manufacturing technology. The NCMS recommends several approaches for addressing the technology and business needs of the U.S. Nanomanufacturing Industry, while responsibly translating the benefits of new products into applications for societal benefit.

Critical investment, business and regulation-related issues need to be addressed concurrently and collaboratively by State and Federal policymakers in order to maintain the current high momentum of innovation in nanotechnology advances. Long-term National investment and stimulation of public-private-academic partnerships are required for developing the fundamental science base, facilitating technology transition to applied research, and demonstrating credible nanotechnology-enabled applications and novel products that are perceived as meaningful to our quality of life. The potential risks and hazards associated with the more revolutionary envisioned nanotechnology applications need to be assessed and disseminated widely by trusted sources to raise the public's awareness, and thereby gain societal confidence. Strong incentives will help resulting innovations to be swiftly translated by private industry into technology demonstrations and product applications that help enhance the public's awareness and acceptance. This will require dramatic changes in business strategy and unprecedented levels of public-private regulatory collaborations to responsibly commercialize future nanoproduct applications. Such levels of sophistication and vertical integration do not yet exist in the industry.

Table 6-1 lists several approaches and strategies for addressing clusters of identified barriers to the nanomanufacturing industry.

Table 6-1. Strategies to Address Critical Identified Barriers Faced by the U.S. Nanomanufacturing Industry

INDUSTRY BARRIER(S)	RECOMMENDATION(S)
High cost of processing/ Process scalability issues/ Lack of development tools	▪ Collaborative R&D in value-chains ▪ R&D to reduce/combine process steps ▪ R&D in new equipment and to improve product yields
Long time-to-market/ Unclear societal benefits	▪ Government incentives for private R&D investments ▪ Raise public awareness of benefits via successes ▪ Promote supplier/end-user partnerships
Insufficient investment capital	▪ Government investment in pre-competitive R&D ▪ Stimulate market pull via end-users ▪ Mentor start-ups for attracting investment
IP issues	▪ New business models for nanotech value-chains ▪ Legal reform, train legal and judicial professionals ▪ Streamline partnering with academia and National Labs ▪ Facilitate supplier/end-user partnerships
Shortage of qualified manpower/ Multi-disciplinary aspects	▪ Retrain tech workforce in basic science/testing/quality ▪ Attract students to science and engineering careers
Regulatory and safety concerns/ Environmental and toxicity issues	▪ Streamline permit/product approvals at agencies ▪ Increase government-sponsored R&D ▪ Broader dissemination of findings ▪ Balanced legislation and regulatory practices

6.2.1 Government-Led Public-Private Collaborations

Government support of nanotechnology is critical. It is unlikely that the field of nanotechnology will reach maturity (like other traditional physical science-based industries did) for a long time – i.e. the proverbial “valley-of-death” gap in funding technology commercialization where the government considers it too applied for additional funding, and industry considers it too embryonic for adoption. Private and institutional investments will increase faster when some of the fundamental technical issues of process scalability and cost for production of active nanocomponents as well as risks related to nanomanufacturing have been more comprehensively addressed, and the economic returns and value propositions of nanotechnology better quantified through collaborative R&D in targeted industry applications.

C.K. Prahalad[2] [20] proposes a new breed of public-private investments in nanotechnology “ecosystems” – these may be defined as loose frameworks of multiple nanotechnology solution providers and key end-users, working together in large market-segmented technology networks. These ecosystems would entail higher levels of information sharing, requiring a greater level of trust as well as special incentives in order to engage and retain technology partners – not unlike the Japanese “*kieretsus*” used by successful automotive manufacturers.

The strategies available for effectively addressing these challenges require greater involvement of the government in:

- Sponsoring priority basic science, safety and environmental research to avert the

[2] Personal communications on March 28, 2006 in San Diego, CA with C.K. Prahalad, Harvey C. Fruehauf Professor of Corporate Strategy & International Business, Co-Director Center for Global Resource Leverage: India, and University of Michigan, Stephen M. Ross School of Business.

controversies that constrained other innovations (such as biotechnology and genetically modified foods) to introduce appropriate and timely regulatory practices.

- Providing the extensive infrastructure necessary for U.S.-based stakeholders to conduct the multidisciplinary R&D critical for public acceptance
- Promoting responsible commercialization practices.

Government can help industry better execute these needs by defining National priorities, and creating incentives for industrial adopters of nanotechnology, in order to accelerate the broad-based translation of nanotechnology advances across multiple industry sectors. In order to gain greater societal support, public-private collaborative efforts in applied nanotechnology should target nearer-term National concerns such as increasing productivity and profitability in manufacturing, improving energy resources and utilization, reducing environmental impact, enhancing healthcare with better pharmaceuticals, improving agriculture and food production, and expanding the capabilities of computational and information technologies.

Specific tactical areas where government involvement in nanotechnology can have high National impact while leveraging private investments include:

1. Incentives favoring longer-term investments (e.g. tax-free bonds for financing, tax credits for long-term capital investments, reduced capital gains tax rates, investment-specific loan guarantees, etc.)
2. Promoting strategic alliances for researchers (at academic and National Labs) and start-ups with larger players or end-users
3. Providing mentorship and business planning assistance to small businesses to identify key technology benefits (needed to attract private capital)
4. Underwriting and disseminating “good science” research and public education into the long-term issues related to waste disposal, safety and regulations
5. Undertaking tort and legal reform against frivolous lawsuits, which will provide developers greater immunity and protection once their products are Federally approved.

Aggressive technology transfer practices can be pursued through innovative relationships between academia and industry in nanotechnology developments. For example, NNI programs awarded to university-based researchers could be better structured to encourage industrial partners to pursue their economic goals. This can take the form of the NNI working with academic organizations in granting companies non-exclusive or royalty-free, fully paid up, irrevocable, perpetual licenses to make, use or sell nanotechnology products under university-held patents. Universities could also contribute no-cost assistance to corporations implementing inventions in their facilities, thereby training new workers.

Finally, State governments and economic development bodies can significantly assist small and large businesses by promoting nano-incubator and user facilities with streamlined access. By working with university technology transfer organizations, they can facilitate better access to nanotechnology resources and training available in public educational institutions, thereby stimulating new partnerships with entrepreneurs. Offering matching funds and other seed incentives to organizations pursuing Federal nanotechnology programs would provide further impetus for businesses and researchers to partner in commercialization nanotechnology ventures. Several U.S. States have already initiated these next-generation technology partnerships.

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Appendix A – Cross Industry Survey

NCMS-NSF Cross-Industry Survey of U.S. Nanomanufacturing Industry

Online Survey Questionnaire

(Survey questions are in **bold**;
Survey response options/guidelines/rating scales are shown in box [ ] parentheses)

1. **What choice best describes your organization/firm's primary (envisioned) role in nanomanufacturing? Select one.**
   [End-user/Consumer of products incorporating nanotechnology
   Manufacturer/Integrator of products incorporating nanotechnology
   Component Supplier/Vendor of products incorporating nanotechnology
   Service Supplier (Engineering, Consulting, Training)
   Contract R&D/Test lab
   Education/Academia
   Government Agency/Lab]

2. **What application markets/end uses does your organization aim to serve with nanotechnology products? Choose all that apply.**
   [Aerospace
   Automotive
   Off-Highway/Other Transportation
   Machine-tools/Heavy machinery
   Fabricated Metal/Polymer Products
   Chemicals/Process
   Metals, Mining/Production
   Energy & Utilities
   Consumer Products/Textiles
   Housing/Construction
   Food & Agriculture
   Pharmaceuticals/Biomedical/Biotechnology
   Electronics/Semiconductor
   Computing, IT & Telecommunications
   Tooling/Equipment/Logistics & Distribution
   Sensing, Environmental & Security]

3. **How is your company/organization changing its strategy to accommodate nanomanufacturing technologies?** [1 = Coping poorly, 5 = Coping very well]

4. **Please rate your company/organization's capacity (i.e., resources, capital, manpower) for handling change to accommodate nanomanufacturing technologies** [1 = Low capacity, 5 = High capacity]

5. **Please rate your company/organization's infrastructure for pursuing new nanomanufacturing technologies** [1 = Insufficient, 5 = Plentiful]

6. **How would you rate your company's urgency for commercializing new nanomanufacturing advances into product?** [1 = Low priority, 5 = High priority]

7. **How is your company/organization developing nanomanufacturing technology products- internally or through partnering with external organizations?** [1 = Strictly internal efforts, 3 = Combination of internal & collaborative work, 5 = Mostly collaboratively]

8. **What is the chief driver for collaborating or partnering?** [Partnering to extend development and commercialization capabilities globally; Partnering with young companies to access new science and developments more rapidly; Partnering to access capabilities and capital equipment]

9. **How many personnel are involved in your company/organization's nanomanufacturing commercialization activities?** [1 = Less than 10 staff; 2 = 11-20 staff; 3 = 21-50 staff; 4 = 51-100 staff; 5 = More than 100 staff]

10. **When does your company/organization expect to field commercial products containing nanomanufacturing technology?** [1 = Already marketing nanotechnology products; 2= Within 1 year; 3 = Within 3 years; 4 = Between 3-5 years; 5 = More than 5 years out]

11. **What types of nanotechnology products have been commercialized or are being developed in your organization?** [List of common nano-products; Other ______ state in 50 words or less]

12. **What is your opinion regarding the government's role in development of nanomanufacturing technologies?** [1 = Govt. involvement is not important, 2 = let industry take the initiative and Govt. partially fund it; 3 = Govt. should only support pre-commercial nanomanufacturing. technology demonstrations; 4 = Govt. should invest heavily and offer strong incentives to industry; 5 = Govt. should take the lead in nanomanufacturing investments]

13. **What are the key challenges facing the U.S. nanomanufacturing industry? Pick the top 5 issues.** [High cost of processing; Environmental, regulatory or safety concerns; Process scalability; Materials variability; Availability of raw materials; Lack of development tools; Manufacturing resources do not keep pace with new product developments; Making and maintaining productive alliances at all levels; Shortage of qualified manpower; Insufficient investment capital; Foreign competition; Government policy issues; Intellectual property issues; Unattractive market potential; Multi-disciplinary aspects and resource needs; Perception that nanotechnology products are a long way from commercialization; Perception that

societal benefits of nanotechnology are not yet recognized; Other ______state in 50 words or less]

14. **What are your 3 preferred delivery mechanisms for technology transfer on nanotechnology advances?** [Industry print media; Online media; Industry trade shows/conferences; e-Learning modules; Technology demonstrations at academic or research facilities; Consortia/partnerships; Other _______]

15. **For notification of the survey results and to download the final report, please provide your contact information below. Your comments and feedback on this survey are welcomed – please type them in the box (less than 50 words)** [Full Name, Firm, Location/State, E-mail; Survey Comments].

Appendix B – Nanotechnology Products and Major Application Markets

Nanotechnology Products and Major Application Markets

(Primary markets shown in green, as indicated by aggregate survey responses)

NANOTECHNOLOGY PRODUCT(S) \ APPLICATION MARKET(S)	Nano-Tools, Equipment, Logistics	Electronics & Semiconductors	Computing, IT & Telecom	Aerospace	Automotive	Chemicals & Processing	Sensing, Environmental & Security	Energy & Utilities	Fabricated Products	Consumer Products & Textiles	Pharma, Biomedical & Biotech	Off-Highway & Transportation	Machine-tools & Machinery	Housing & Construction	Food & Agriculture	Metals, Mining & Material Production
Semiconductors, Nanowires, Lithography & Print Products	**X**	**X**	X	X	**X**	**X**	X	X	X	X	**X**		X			X
Coatings, Paints, Thin-films and Particulates	**X**	**X**	X	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Nano-structured Particles, Nanotubes & Self-Assembly	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	X	**X**	**X**	**X**		**X**	**X**
Drug Delivery & Diagnostic Systems, Medical Implants	X	**X**	**X**			X	X		X	X	**X**				X	
Nano-Bio, Nanofluidics & Tissue Engineering Products	X	X	X				X		X	X	**X**				X	
Catalysis, Battery, Fuel Cell & Filtration Products	X				**X**	**X**	X	**X**	X	X	**X**	X			X	X
Environmental Sensing & Remediation Products	X	**X**		X	X	**X**	X	X	X	X	X	X			X	X
Defense, Security & Protection Gear	X	X		**X**	X		X	X	X	X	X					X
Electronic Devices, Displays & Optoelectronics	X	X	X	X	X		**X**	X	X	X	X				X	
Nano-Manipulation, Visualization, Biomarkers, Q-Dots	X	X	X			X	X		X	X	**X**		X		X	X
Computing, Design, Imaging Tools & Products		X	X													
Personal Care, Nanofluids & Colloids						X				X	X				X	X
Convergence Products (Nano-Bio-IT-Cognitive)			X								X					
Other															X	